DEVELOPMENT OF ELECTRIC VEHICLE PROTOTYPE

(DESIGN OF BATTERY PACK FOR ELECTRIC VEHICLE BASED ON LEAD ACID BATTERY)

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Electrical and Electronics Engineering

Faculty of Engineering and Science
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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF ELECTRIC VEHICLE PROTOTYPE : DESIGN OF BATTERY PACK FOR ELECTRIC VEHICLE BASED ON LEAD ACID BATTERY"** was prepared by **JAYSON PHUAN ZHENG YI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronics Engineering at Universiti Tunku Abdul Rahman.

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DESIGN OF BATTERY PACK FOR ELECTRIC VEHICLE BASED ON LEAD ACID BATTERY

ABSTRACT

In these modern days, electric vehicles are well known for its efficiency, it would be a cost saving choice compared to the ICE car, due to its advantages such as silent engine, zero emission which are totally green to the environment. However the selection of a suitable battery type such as lead acid, NiMH, Lithium ion in the long run plays a very important role in the construction or design of the electric vehicle due to its function and also the physical aspects. In terms of the functionality, the vehicle must be able to provide sufficient energy to allow the car to move or accelerate and at the same time, having a long lifespan or constant power supplied to the vehicle. Taking this into consideration, I will be further discussing on the characteristics and the battery profile of a lead acid battery that will be the main source of power for the electric vehicle.

Keywords : **characteristics and battery profile, lead acid battery,**

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LIST OF SYMBOLS / ABBREVIATIONS

PWM	Pulse Width Modulation
SCR	Silicon Controlled Rectifier
SOC	State of Charge
LED	Light Emitting Diode

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CHAPTER 1

INTRODUCTION

1.1 Background

Lead acid batteries were first found in the 1748 to be exact by Benjamin Franklin where he first defines the term 'battery' to describe an array of charged glass plates. Then from 1780 to 1786, Luigi Galvani further researched on the electric basis of nerve pulses and provides the cornerstone of research for the next inventor which goes by the name of Alessandro Volta. He continued the work of Luigi Galvani through executing and experimenting on the lead acid batteries and found out it generates electrical current from a specific set of chemical reactions between dissimilar metals consisting of zinc and silver disks separated by a porous nonconductive material that is saturated with seawater. When it is stacked in a particular manner, a voltage could be measured across each silver and zinc disk. Lead Acid batteries are known to be one of the oldest types of rechargeable battery. Alessandro Volta's voltaic pile was known to be the first wet cell battery that produces a reliable and steady current of electricity to a load. In 1859, a French physicist that is known to be Gaston Planté developed the first commercial and practical storage lead acid battery that is rechargeable which is primarily used in cars and other daily applications today.

When technology started to progress in the mid-1970s, a few researches came together to develop a maintenance free lead acid battery that was able to operate in any position. The maintenance free lead acid battery works where the liquid electrolyte is transformed into moistened separators and the enclosure was sealed. Besides that, additional safety valves is added allowing the venting of gas to take place during the charging and discharging process. All batteries including lead acid batteries are mainly used to provide starting or deep cycle power where the only difference is the amount and duration of the power delivered. In a usual car, lead acid battery is used as starting battery where it delivers a short burst of high power to crank the engine. This starter battery includes many thin lead plates that allows quick discharging of large energy over a short period of time but the down side of this is its inability to withstand deep discharging due to the thin lead plates for starter currents that corrodes quickly under deep discharge condition and also when it undergoes charging process. If these batteries are discharged completely for more than a few times, it will tend to cause damage to the battery. On the other hand, deep cycle batteries tend to have thicker lead plates which help to tolerate deep discharges giving us a lower but steady level of power for a longer period of time compared to a starting battery.

1.2 Aims and Objectives

The aim of this project is to observe the behaviour of a standard lead acid battery and to understand the characteristics and profile of the battery under load condition and also without load condition. Besides that, the other main objective of this project is to understand the SOC (State of Charge) of lead acid batteries in order to supply an optimum and constant amount of power to different parts of an electric vehicle. We have to understand the characteristics of a lead acid battery to accommodate the Battery Management System and also to calculate how long the lead acid battery will be able to perform on the road under load. Besides that, we have to learn about the charging rate and discharging rate of the battery in order to find out the charging duration until full charge and discharging duration. In addition, another objective to further improve the performance of lead acid battery in an electric vehicle is the to build a solar charger for lead acid battery. This will contribute to the charging of the battery on the road during the day at the same time, in case if the battery is in need of charging and there is no charging station around, the technique of solar charging can be useful.

CHAPTER 2

LITERATURE REVIEW

2.1 Advantages and Disadvantages of a Lead Acid Battery

There is much type of batteries that is capable and suitable to be the main power source of an electric vehicle but the most affordable, easily attainable and available battery in the market is the lead acid battery where it is low cost and reliable as it has gone through over 140 years of research and development. Besides that, a lead acid battery is robust where it has the capability to tolerate abuse or in other words, it is tough. If we were to make a comparison, the lead acid battery has a big advantage over lithium ion battery in terms of its tolerance to overcharging. The lithium ion batteries have a low tolerance to overcharging where if it is allowed to overcharge; it tends to shorten the lifespan of the battery. For example, our laptop battery is made out of lithium ion battery and if we were to leave the battery in its compartment even if it is at full charge, we notice that the lifespan of the battery drops where the usage duration of the laptop decreases. In addition, a lead acid battery tends to have low internal impedance hence allowing it the capability to deliver high currents. The usual shelf life of a standard lead acid battery is 9 months before use and it is suggested to charge every 2 months if it is sitting on the shelf. High temperature will also lead to an increase of self discharging rate. On the other hand, if it is stored without any electrolyte, it has indefinite shelf life. Another advantage that lead acid battery acquires over lithium ion battery is that it can be left on trickle charging or float charge for a prolonged period of time where lithium ion batteries cannot apply this type of charging method. This trickle charging method can be defined as a charging current that can be applied to the battery without damaging it or better known as slow charge. The float charging is known as a constant voltage charger that operates at a low voltage where it keeps the charging current low hence decreases the damage done by the high current overcharging. Lead acid batteries also have a wide range of sizes and capacities available with many suppliers worldwide. They are also known as the world’s most recycled product.

There are also a few disadvantages to the lead acid battery where in its physical perspective; it is very heavy and bulky due to its battery construction. The lead acid batteries also tend to have the danger of overheating during charging and it is not suitable for fast charging. Besides that, it have a typical short cycle life of 300 to 500 cycles and must be stored in a charged state when the electrolyte is introduced in order to slow down deterioration of the active chemicals. Another big disadvantage of a lead acid battery is that sulphation tends to take place if a battery is kept on shelf for a long period in a complete discharge state, low state of charge or the electrolyte is low due to excessive water loss due to overcharging. This increases the internal resistance of a battery due to the formation of large lead sulphation which is unable to be converted back to lead, sulphuric acid and lead dioxide when charging process takes place. The worst case scenario that could take place is that crystals may cause distortion and shorting of the plates. But the only good side is this issue can be corrected by slow charging at low current with a high voltage compared to the usual voltage. These batteries also contain toxic chemicals that might leak out over time and it will be hazardous for users or even during operations. In addition, shedding also occurs where it is the loss of material from the plates due to excessive charging rate. This causes chunks of lead on the bottom of the cell resulting to the formation of holes in the plates which will permanently damage the performance of the battery. Gassing also occurs when excessive charging takes place, resulting to a loss of electrolyte where gassing is known to be the release of bubbles of hydrogen and oxygen in the electrolyte during the charging process. This may cause an explosive atmosphere if action is not taken quickly.

2.2 Battery Construction

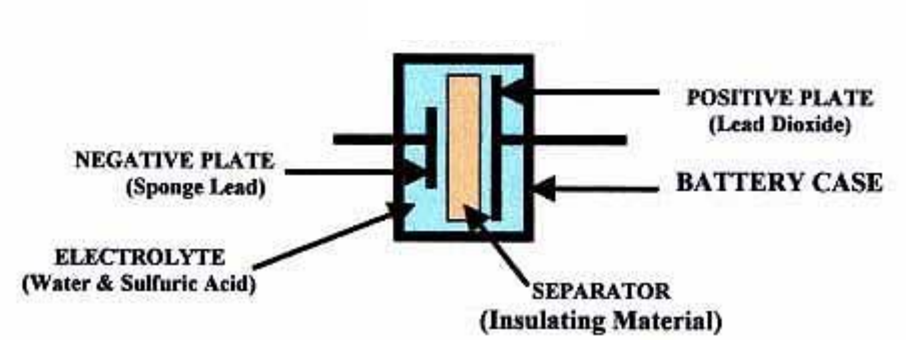


Figure 2—1: Standard Single Cell Lead Acid Battery

A standard lead acid battery consists of several single cells connected in series where each cell produces approximately 2V and usually a 12V battery have six single cells in series which produces a battery that is fully charge with an output of 12.3V to 12.8V as shown in the figure below. In the battery, it has two lead plates which are the positive plate that is covered with a paste of lead dioxide and a negative plate that is made of sponge lead. There is an insulating material that separates both plates and the plates will be enclosed in a plastic battery case which is submersed in water and sulphuric acid which is the electrolyte liquid for the battery as shown in the figure above. Lead acid cells in the battery will produce voltage when it receives a charging voltage of 2.1V and above from a battery charger where it doesn’t generate voltage by itself but they are capable to store a charge from another source. Lead acid battery is known to be storage batteries for this as they works as a charge storing device. The amount of charge a lead acid battery can store is depending on the size of the battery plates and the amount of electrolyte. The unit that is used to measure the capacity of the battery is known as Ampere-Hour (Ah). For example, if a battery has 75Ah means it has the capability to discharge 75A for one hour or 1A for 75 hours. The total capacity can be increase by connecting a few lead acid batteries in parallel. (Progressive Dynamics Inc, 2006)

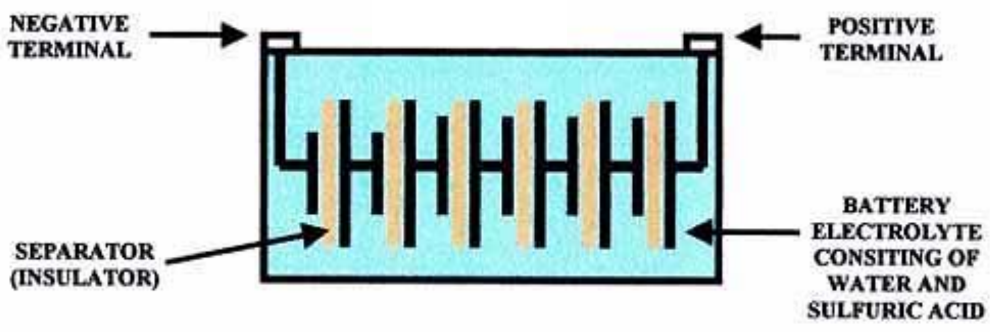


Figure 2—2: Standard Lead Acid Battery

In order to discharge the battery, a load (light bulb) is used to drain the battery and when it is connected, the chemical reaction between the sulphuric acid and lead plates will produce electricity to the light bulb. As electricity is supplied to power up the light bulb, internally, the sulphation process takes place where lead sulphate starts to coat both the positive and negative plates where this process usually occurs during a discharge cycle. It will become worst when the discharging process is prolonged where the lead sulphate coats more and more of the plates causing the voltage of the battery to drop from its original fully charged state as seen in the figure below. (Progressive Dynamics Inc, 2006)

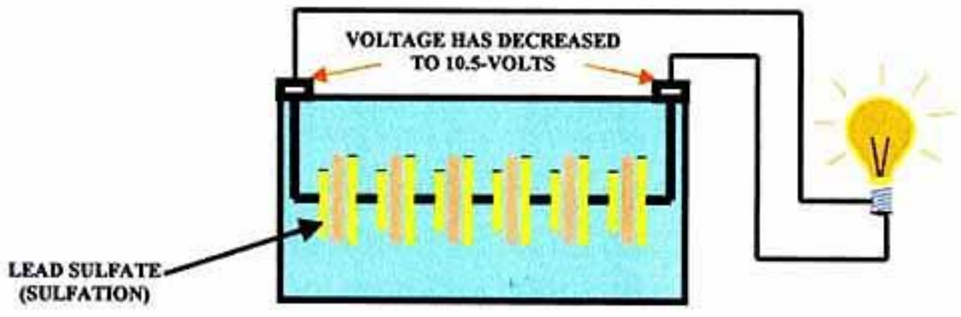


Figure 2—3: Sulphation

If a battery is being discharged below 10.5V, it will damage the battery and also decrease its capacity. As the lead sulphate starts to coat most of the battery plates, it must not be left discharged for a prolonged period of time due to the hardening of the lead sulphate where initially lead sulphate is a soft material that is able to be converted back into lead and sulphuric acid. This will further cause the formation of hard crystals which cripple the ability of the battery to charge if we were to use a standard fixed voltage battery charger. (Progressive Dynamics Inc, 2006)

2.3 Method of Charging the Lead Acid Battery

There are a few methods that are available or known to be able to charge a lead acid battery but in this case, we are focusing the constant current-constant voltage charging method where it uses a voltage based algorithm that is the same with the lithium ion battery charging method too where a usual charge time for a sealed lead acid battery can be up to 16 hours. There is a faster way to charge the battery which is known as the fast battery charging method where it uses a high current pulse that is pumped into the battery at a faster rate with high capacity of current which will cut down on the charging time but at the same time, if it is not under close supervision, it might damage the battery due to its high current pumping into the battery. The constant current-constant voltage charging method will be explained and further discussed in 3 sections which is the constant current charge, constant voltage (topping charge) and the float (trickle charge).

2.3.1 Constant Current Charging

This constant current charging is the first phase of the recharging of the batteries where it usually takes up 50% of the charging period. Usually a battery that has just been discharge have a voltage of 11.50V approximately and when it undergoes the charging process, this constant current charging will ensure that the voltage of the battery rises to a voltage that is determined by the characteristics of the battery itself which will be approximately 13V with a relatively uniform current flow charging the battery.

This helps to eliminate the imbalances of cells and batteries that are connected in series which is the most appropriate for cyclic operation where a battery is required to obtain a full charge overnight. In this phase, the battery will be charged up to 70% approximately in the range of 4-7 hours and the other 30% is charged using the trickle charging method. The change of phase from the constant current charging to the next phase occurs when the battery reaches its voltage limit. This method is widely used for most battery chargers. (Cadex Electronics, 2011)

2.3.2 Topping (Constant) Charging

This charging takes place when the lead acid battery voltage increases and stays constant at its voltage limit which will be in the range of 12V to 13V. For every standard lead acid battery, the approximate pre-determined battery is 12.6V. Once it reaches its saturated voltage, the current that is applied into the battery will start to decrease where it leads to a full charge condition once it reaches 3% of the rated current. This process is mainly to ensure that the battery cells remains at the same voltage in the battery pack. During the charging and discharging process, each cell in the lead acid battery might react differently to other cells that are in the battery due to certain factors such as the quantity of charge in each cell is different. (Bigginhill, 2006) . Hence during the charging process, this topping charge will help to give a slight overcharge to bring the other cells up to full charge. Topping charge should be applied every six months to avoid voltage drop below 2.10V per cell. (Cadex Electronics, 2011)

The stronger cells in the battery will absorb the overcharge through the dissipation of heat from the boiling and gassing while the weaker cells will absorb the current from the overcharge until it is sufficient. This topping charge period should be long enough to help pull the cells in the battery up to a fully charged condition.

This topping charge is also used to complete the process of fast charging where it is left to charge for at least 30 minutes with a low current. If the battery is used regularly, it will tend to have high leakage current which means when it is left on shelf, the process of self discharging happens rapidly. This high rate of leakage might not attain this low saturation current.

A precautionary step should be taken to ensure that overcharging doesn't take place for too long of a time because once the lead acid battery is being overcharged, the electrochemical process will cause it to heat up and boil. The phenomenon of hydrogen gas been let off at the negative cathode plate and oxygen gas being let off at the positive anode takes place due to any charging current beyond that required to liberate the small amount of sulphate radicals from the plates, ionizes the water in the electrolyte. Hence, triggering the process of electrolysis where it separates the water into hydrogen and oxygen gas. While this process occurs to form water vapour, the presence of flammable and potentially explosive hydrogen gas will encourage charging to be done in a well ventilated area. If this is not conducted properly, it will result in a battery explosion due to the hydrogen gas that is being released by the boiling acid. This brings more bad news for sealed lead acid battery where it have a higher chance of an explosion to happen as it has nowhere for the gas to exit hence indirectly building up the pressure in the case leading to an explosion. On the other hand, at low temperature, the electrolyte might freeze up, affecting the performance of the battery. The safe operating temperature for a battery pack is usually 80 Fahrenheit or 26.37 degree celsius.

2.3.3 Float (Trickle) Charge

The float charging is also known as the trickle charging method where its definition is a charging current that can be applied to the battery without damaging it or simply defined as slow charge. This process keeps the voltage at a constant where else the current will be operating at a very low level. The float charge compensates for the self discharging process that happens when the battery is put on shelf where it will self discharge at a rate of 2% - 3% every month. Aging batteries will be an issue when the float charge is set due to the different age condition that each of the cells have. This can be seen where a float current that is too high for the aging cell will starve the stronger cells in the same battery causing sulfation due to undercharging.

The figure below shows the characteristics of the constant current constant voltage charging.

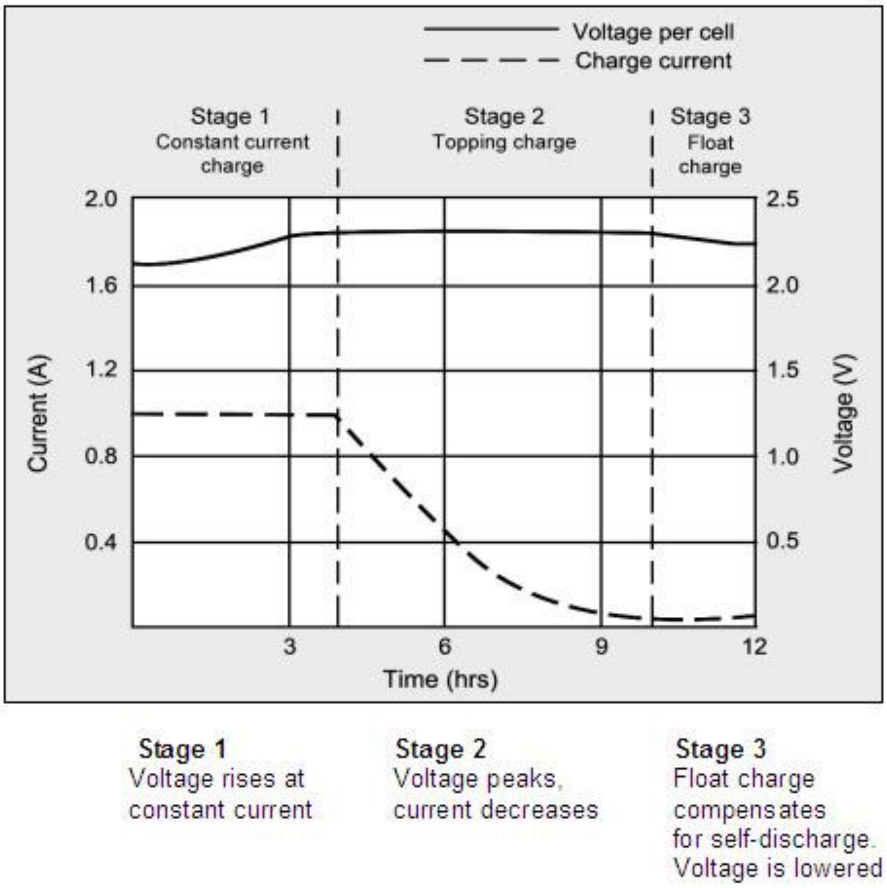


Figure 2—4 : Constant-Current Constant-Voltage Charging Method

2.4 State of Charge (SOC)

To further understand the state of charge, or also known in short as SOC, there are also other battery parameters that we have to look into such as the discharge rate, depth of discharge and also state of discharge or known as SOD. First, the discharge rate can be defined as the current at which a battery is discharged and can be expressed as Q/h rate where Q is the battery capacity and h is known as the discharge time in terms of hours. The depth of discharge is known as the percentage of battery capacity (rated capacity) to which a battery is discharged. If the withdrawal of at least 80% of the battery (rated) capacity is known as the deep discharge state. (Von Wentzel, 2008). Hence this leads to the state of charge where it is closely related to this two terms where SOC is defined as the present capacity of a battery where it is the amount of capacity that remains after discharging from a top-of-charge condition. It is known that every cell have a different range of SOC hence leading to a performance difference among the batteries in the pack. This helps to balance up the charging and discharging in order to maximize the battery pack lifespan and the energy efficiency. This means, with the combination of battery voltage, internal resistance, and the amount of sulphuric acid combined with the plates at any one time are the indicators of how much energy is in the battery for a given time. It is understood that the SOC is given as a percentage of its fully charged value, for example, if it is at 75% means that the amount of battery capacity is available at 75% and shows that 25% has been used. In a battery, the rate of which the energy is drawn affects the overall amount of energy available from the battery. Give example, if a 100Ah battery is rated at 10 hour rate, that means that at over 10 hour, there are 100Ah available or in other words, the load can draw up to 10A per hour up to 10 hours where 10A X 10H = 100Ah. A standard 12V lead acid battery have a usual 100% state of charge that shows that it's fully charged with a voltage reading of 12.6V on average and on the other hand, when that state of charge is at 0%, the voltage reading is usually average at 11.8V. Once again, this may differ from different lead acid batteries due to its own battery characteristics as mentioned earlier.

The relationship between the state of charge with the battery voltage can be seen in the figure below. (Woodbank Communications Ltd, 2005)

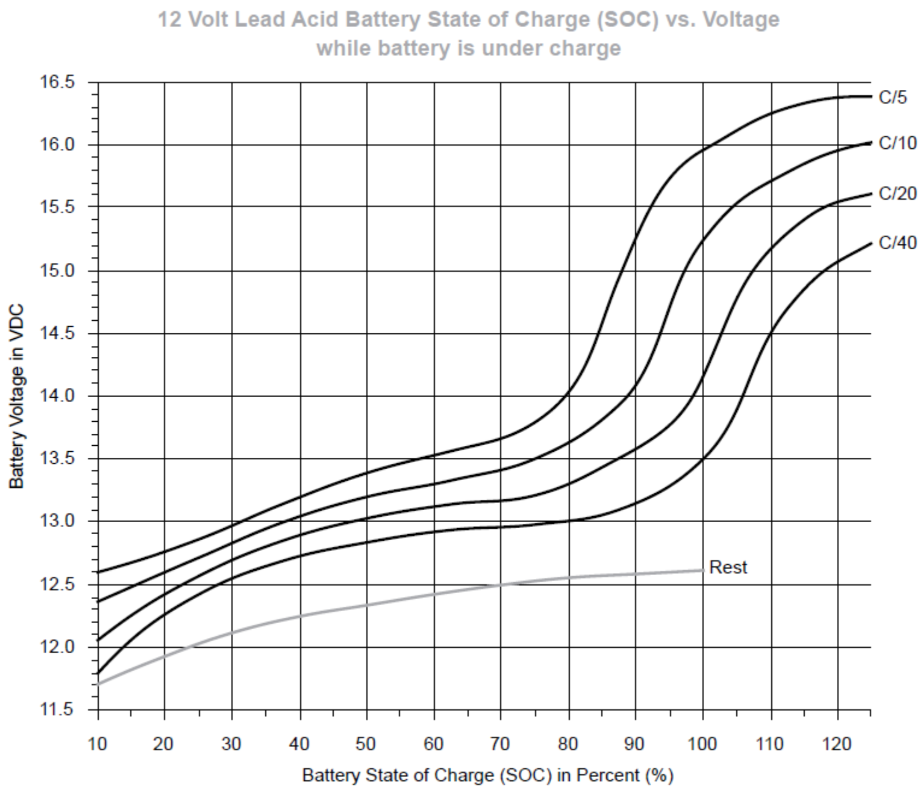


Figure 2—5: Voltage vs State of Charge (12V Battery)

The charging and discharging current in a lead acid battery is measured in C-rate where most battery are usually set to have a charging and discharging current characteristics of 1C. For example, if the C-rate is set to discharge at 1C (also known as one hour discharge) on a 500mAh battery, it will discharge 500mAh in a period of an hour. Instead, if the C-rate is set at 2C, the battery of 500mAh will provide an output of 1000mAh for a shorter period of time at an approximation of 30 minutes. Based on the research done, the standardized C-rate of the battery is at 0.05 (20 hour discharge). At this slow discharging rate, a 100% capacity (ability to provide current from the battery for 20 hours in this case) is almost impossible. Usually a capacity of a lead acid battery is measured using a battery analyzer where it is displayed in a percentage rating. For example, a 500mAh battery provides current for an hour at 1C meaning that it has a 100% capacity but a battery has 50% capacity when the battery only supplies current at a time period of 30 minutes. To summarize, if the battery is set to discharge at a lower C-rate, we will obtain a longer time period for the battery to discharge (higher capacity). Hence with high C-rate, the capacity of the battery will deteriorate sharply. The discharging profile with various C-rates can be further seen in the figure below.

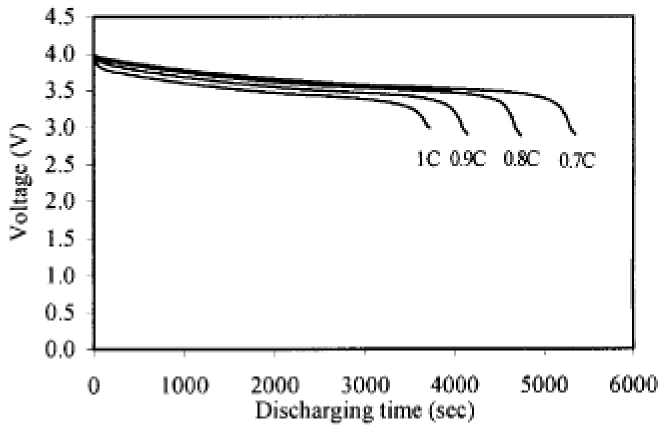


Figure 2—6 : Discharging Profile with various C-Rate

The usual traditional way to measure the state of charge is through hydrometer where it measures the specific gravity of the electrolyte and with a little calculation, we can obtain the state of charge of the particular battery. As time passes, it is known that voltage can also be used to determine the battery state of charge with a few calculations. The voltage measurement is a better option preferred to than the hydrometer is because the hydrometer can cause inaccuracy in reading and it contaminates the battery cell. Besides that, we cannot use the hydrometer for this project is because the battery that is provided is sealed lead acid batteries. The figure below shows the usage of a hydrometer.

Figure 2—7 : Hydrometer

There are a few things that are needed to be avoided to ensure that the state of charge does not drop critically for determining its battery efficiency. When the batteries are being charged and discharged, it indirectly affects their state of charge which makes it as a critical factor. To prevent this from happening, try to avoid placing continuous heavy loads on the battery anywhere in their state of charge cycle to avoid fast draining of its battery charge. A battery pack that delivers 100% of its capacity when discharged in 1 hour, for example, might deliver only 50% of its capacity when it is forced to discharge in 20 minutes. When the state of charge is below 20%, we must stop discharging the batteries to ensure that the battery life is not greatly reduced or destroyed due to the high rate discharging. Besides that, make sure that heavy charging is done within 20% to 90% of the state of charge range due to the ability of the lead acid battery to store energy when it is almost full or nearly empty. In the 20% - 90% range, C/10 (divide the capacity by 10) delivers the fastest rate at which it is efficient to charge a lead acid battery. In order to obtain the accurate state of charge reading, the battery must rest for a few hours (2-6 hours or 24 for optimum accuracy) due to the surface charge where if the plates are damaged or sulphated, the battery might give the appearance of being fully charged but instead its capacity is much lesser than that. When measuring the state of charge, we must ensure that the temperature of the room or its surrounding must be almost constant because if the surrounding temperature is too warm, the chemical reactions within the battery will be accelerated and the battery life might be shortened and if the battery gets too cold, the chemical reactions tend to slow down, reducing the battery output. (Woodbank Communications Ltd, 2005). This makes the battery temperature dependent where the available capacity and maximum current both drops at low temperature and increases at higher temperatures. The possibility of freezing is also there for a fully discharged battery at temperatures below zero due to the slowing down of the chemistry process in the battery. Hence in this case, the charging voltage needs to be increased when the temperature falls to ensure that the battery continues to receive charge but on the other hand, it is necessary to provide an upper limit on this raised voltage to ensure that the load equipment that is connected to the battery during the charging process is doesn’t operate out of its specified range. (North Arizona Wind & Sun, 2009) Besides that heat stagnation can also be a problem where it causes thermal runaway where it is defined as a critical condition arising during constant voltage charging process where it is accelerated by increased temperature of the battery in turn releasing energy that further increases the temperature and in the end, it leads to the destruction of the battery. (Von Wentzel, 2008).

2.5 Pulse Width Modulation Solar Charging

2.5.1 Solar Panel Concept

A solar panel is known to be a device that collects the photons of sunlight that are very small packets of electromagnetic radiation energy. Then this energy is converted into electrical current that is used to power up electrical loads. Solar panel has been in demand due to its main factor of using a renewable energy source that is already there. In most cases, the solar panel is used for off-grid living where it is used to power up a location where the main electric utility grid doesn’t go such as a ‘orang asli’ settlement or either many longhouses that is situated in Sarawak. This plays as an advantage to those remote homes where it is no longer necessary to pay huge fees for the installation of electric utility poles and cabling from the nearest main grid access point and this makes it less expensive and it can last long if it is maintained properly. An example of many different types of solar panel can be seen in the figure below.

Figure 2—8 : Solar Panels

In the world today, with the global climate change, it has come to a realization point where solar panel is used in order to reduce the pressure on our atmosphere from the emission of green house gases. The solar panels have no moving parts and require little maintenance. These solar panels could provide as much as 15 to 20 years of free electricity once the initial installation costs is paid. (Seriously Solar, 2005)

2.5.2 Structure of a Solar Panel

The solar panels are also known as photovoltaic panels where these photovoltaic (PV) cells are made out of special materials known as semiconductors like silicon. When the PV cells receive sunlight from the sun, a certain percentage is absorbed into the semiconductor material where the energy inside the semiconductor knocks the electrons loose allowing them to flow freely. The PV cells have one or more electric fields that allow the electrons freed by the light absorption to flow in a certain direction where this flow of electrons is known to be the electrical current. The metal contacts on the top and bottom of the PV cells allows electric current to flow in and out of the cell to the external electrical products. This current, combining with the cell voltage (built in electric field), determines the power that the PV cell that is capable to produce as seen in the figure below. The top junction layer that is made out of N-type semiconductor is necessary for energy conversion while the next layer is the core of the device that works as the absorber layer or also known as the P-N junction and lastly the last layer is the back junction layer made out of P-type semiconductor. (Seale E, 2003)

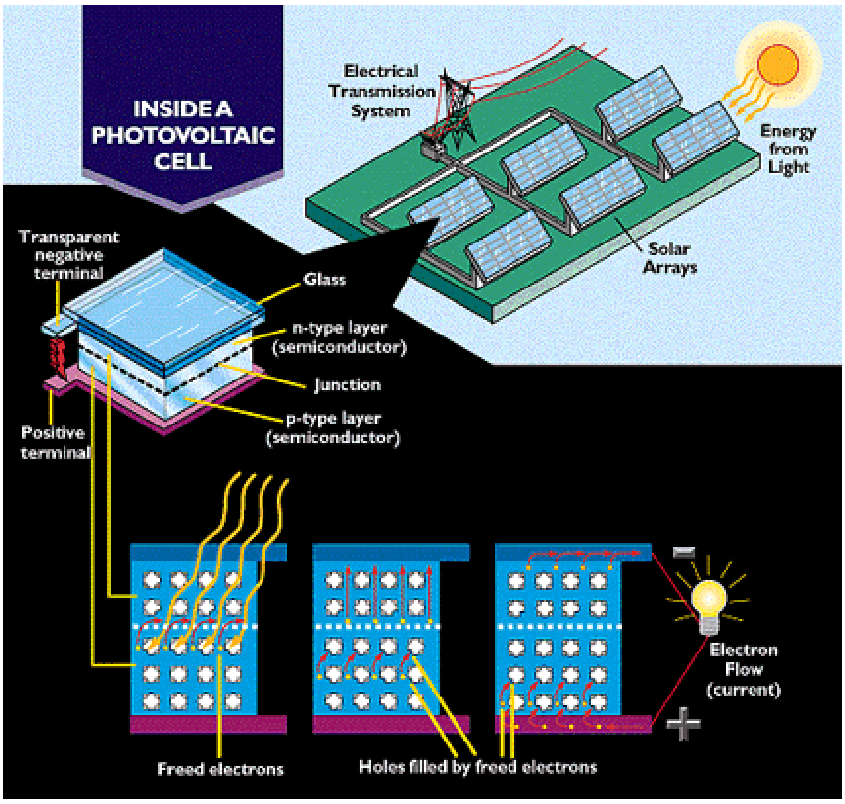


Figure 2—9 : Structure of Solar Panel

2.5.3 Advantages and Characteristics of a PWM Solar Charging

The pulse width modulation solar charging is the most effective way to achieve a constant voltage battery charging using the switching method on the solar system controller's circuit. This is very useful especially for solar charging as the input voltage of the solar panel will vary from time to time. In the modern world, charging a battery with a solar system is complicating, unique and difficult challenge to take on. PWM solar charger uses the same technology with other modern battery chargers in the market. When a battery voltage reaches a certain voltage, the PWM algorithm will reduce the charging current, avoiding heating and gassing on the battery but the charging process of the battery continues with the maximum amount of energy allowed into the battery in the shortest time. This results in a higher charging efficiency with rapid charging and a healthy battery at full capacity.

A few advantages that we can obtain from using this method of charging is a greater use of the solar array energy where we can easily obtain 20% -30% more energy from the solar panels for charging and reduce the wastage of solar energy when the battery is only 50% charged. This will indirectly open up opportunities to reduce the size of the solar array to save costs. (Solarhome.org, 2010). Besides that, we can have a longer battery life, hence reducing the battery disposal problems that requires less maintenance or even cut down on the charging period at the charging station in this case as the solar panel will contribute at least 20% of the charging while the electric vehicle is on the road. In addition, PWM solar charging helps to maintain a high average battery capacity or state of charge. A high battery state of charge is important as we must always keep the battery 'healthy'. The life of a lead acid battery is proportional to the average state of charge and a battery that is maintained above 90% SOC have the capability to provide two to three times more charging and discharging cycle compared to a battery that have a SOC of 50% before it is being recharged again. As the battery is being constantly charged during the day, this will help to maintain the SOC of the battery at a high average and indirectly prolong the life of the battery significantly. (Solarhome.org, 2010). The reduction of battery heating and gassing is also a great advantage of the PWM solar charging where the PWM will do the switching. Since the switching frequency is high (fast switching), there is less time for a gas bubble to build up and at the same time, it charges on a faster and efficient rate hence, minimizing heating and gassing. On the other hand, at the down pulse, gassing is less likely to happen due to the down pulse itself where it apparently helps to break the precursor (a compound that participates in a chemical reaction that produces another compound) to a gas bubble which is most likely to be a cluster of ion. This will help to solve the heat and ventilation problem on the lead acid battery.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In order to understand and grasp the characteristics of a lead acid battery, we are required to build a few modules. The result and data of the project will be further used in the fast charging in order to reduce the charging time without harming the battery health. For the investigation on the lead acid battery, this project consists of three different parts which is:-

a) The Estimation of the State of Charge
b) Lead Acid Battery Charger
c) PWM Solar Charger

3.2 The Estimation of the State of Charge

This module will be used to calculate the state of charge left that is in the lead acid battery where a load will be used to drain the lead acid battery and readings will be taken at every 30 minute interval. In this module, the load that is used is a computer fan that is rated at 12V and two AC lights that is rated at 15W which will simulate both the air conditioning and two headlamps respectively due to budget constrain. From here, the estimation of the state of charge is based on the voltage drop on the lead acid battery and the results obtained will be used in a calculation that will estimate the state of charge percentage in the battery. The result of this method taken with calculation will be just a rough estimation as the only close to accurate method to measure the state of charge is through the usage of hydrometer as mentioned earlier and since this project is dealing with maintenance free lead acid battery, the hydrometer cannot be used to test the electrolytes inside. Hence, this project is carried out using digital voltmeters.

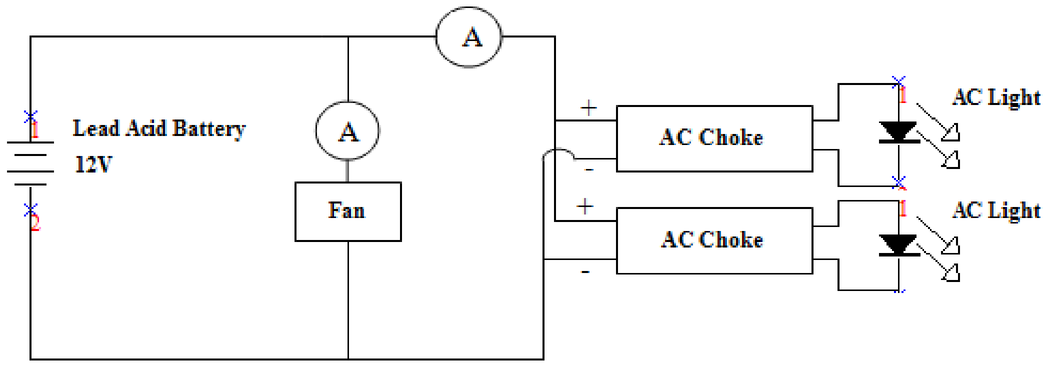


Figure 3—1 : Measuring the State of Charge

In the figure shown above, the module will measure the current flow into the computer fan and also the two AC lights using the ammeter while the AC choke functions to convert DC to AC as the AC light needs AC source to turn on. The reading consists of the current flow into both the AC lights and the battery voltage for further calculation. The calculation involved is as given below:-

$$Voltage = \frac{[\left(\frac{SOC\ Percentage}{100}\right) + 15.5151]}{1.3065}$$

Hence, to find the SOC Percentage,

$$\frac{SOC\ Percentage}{100} + 15.5151 = (voltage)(1.3065)$$

Where,

$$SOC\ Percentage = [(voltage)(1.3065) - 15.5151]\ x\ 100$$

Once the data of the SOC Percentage of that particular lead acid battery is obtained, it will be tabled and a few graphs such as State of Charge vs Time and State of Charge vs Battery Voltage will be sketched.

From here, the module done will be able to give the user a rough estimation of the state of charge of that particular lead acid battery while on the road hence giving early warning to the user if the state of charge is low and needs recharging or when its state of charge is full.

3.3 Lead Acid Battery Charger

The basic idea of this lead acid battery charger is used to charge the lead acid battery once its capacity is near to zero. This lead acid battery charger uses the constant voltage constant current technique to charge the battery and the module is build based on two main components which is LM 317 and BR 106 DC Bridge Rectifier. The usage of both components will be further elaborated next.

3.3.1 BR 106 DC Bridge Rectifier

This module will be powered up from the AC power supply where the power supply has a step-down transformer rated at a ratio of 10:1, rated at 36kVA. This means the power supply receives 240VAC from the main power plug and steps it down to 24VAC where it is seen in the figure below. This 24VAC from the power supply will be supplied into the module where the BR 106 DC Bridge Rectifier will convert AC to DC where it basically rectifies full wave to half wave rectification as seen in the figure below. The BR 106 has a low forward voltage drop and it has the capability to withstand high input voltage up to 420VAC with the maximum input current of 6A.

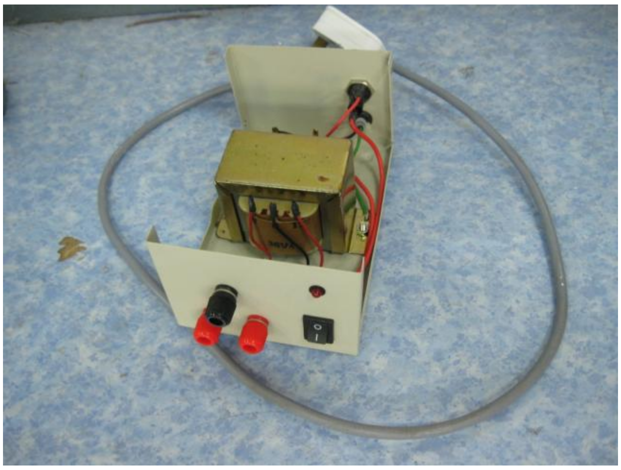


Figure 3—2 : 36 kVA Power Supply

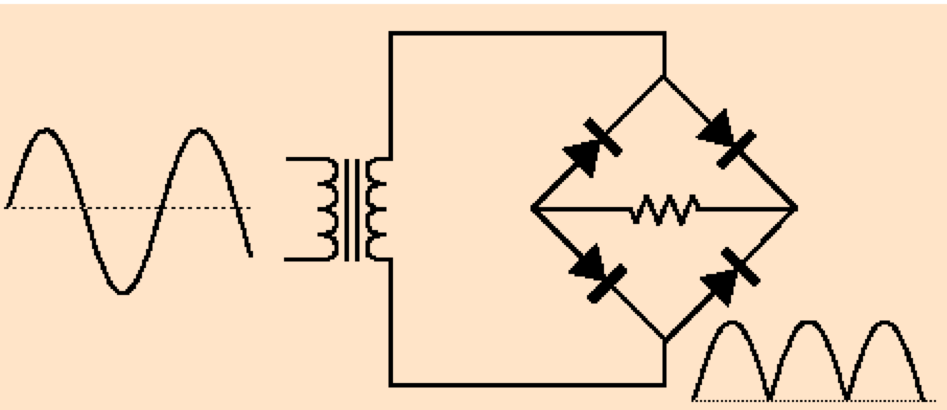


Figure 3—3: Full Wave to Half Wave Rectification

3.3.2 LM317 Adjustable Regulator

The Lm317 is a common regulator that regulates the input voltage to an output that ranges from 1.2V to 37V giving a maximum output current of 1.5A. Besides that, this component has a complete series of protection such as the current limiting and thermal shutdown circuit embedded in the component itself. In this module, the LM317 will work as an adjustable regulator where it regulates the input voltage which will be 24VDC to a voltage lower than that using a potentiometer. A basic voltage regulator circuit can be seen in the figure below:-

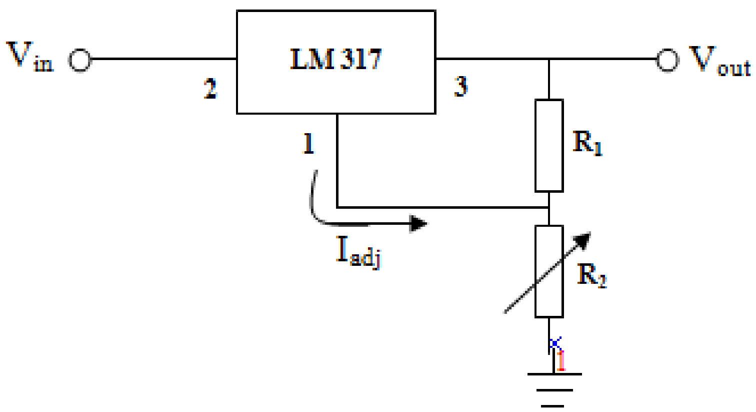


Figure 3—4 : Adjustable Voltage Regulator using LM 317

3.3.3 Design of Lead Acid Battery Charger Circuit

The design of this module consists of both main components of LM 317 and BR 106 DC Bridge Rectifier and a few other components such as capacitors (1000µF/ 40V, 0.22µF) , resistors (0.5Ω/ 5W, 470Ω, 100Ω, 120Ω), a NPN silicon amplifier transistor (BC 548) and a 1kΩ potentiometer. The design of the lead acid battery charger can be seen in the figure below:-

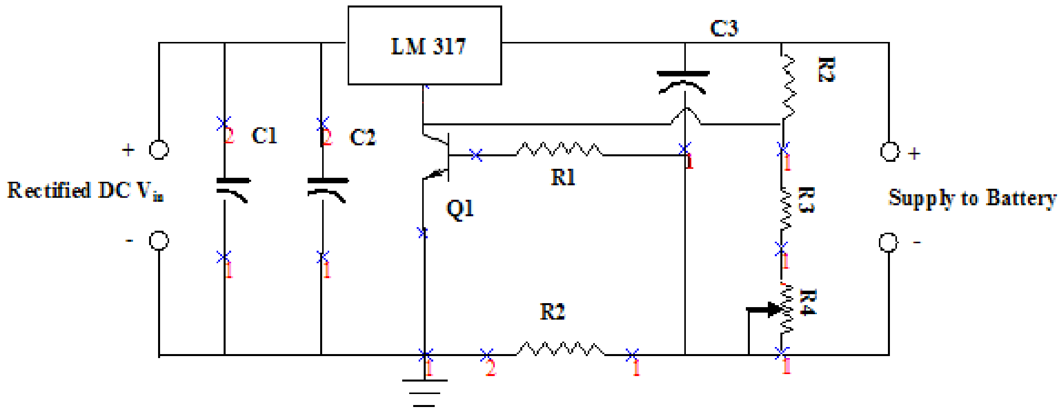


Figure 3—5 : Lead Acid Battery Charger

<u>Component Values</u>

C1 : 1000µF , 40V

C2 : 0.22µF

C3 : 0.22µF

Q1 : BC548

R1 : 100Ω

R2 : 0.5Ω, 5W

R3 : 120Ω

R4 : 1kΩ Potentiometer

The lead acid battery charger shown is designed to charge the battery with 1/10 of its Ah value and can only allow charging up to 1.5A as mentioned in the LM 317 datasheet. Hence the maximum capacity of lead acid battery that can be charged is up to 15Ah only. Based on the circuit, the 1kΩ potentiometer controls the voltage output into the battery where the voltage output from the voltage regulator is predicted to be in the range of 12V to 18V. C1 and C2 capacitor functions to reduce the ripple on the input voltage going into the input of the LM 317. If the voltage output needed to be tweaked, the potentiometer will be adjusted hence sending a V_{adj} back to the adjust pin hence changing the output voltage from the LM 317. On another hand, the BC 548 works as a protection circuit where if the voltage or current exceeds a certain limit, it will trigger the base of the transistor and connects the adjust pin to ground hence, giving no output voltage.

3.4 PWM Solar Charger for Lead Acid Battery

In this module, it can be divided into a few sub-modules that is necessary to complement each other to ensure that the module reaches its fullest capability. Most common solar chargers use an auxiliary power source to assist in the charging of the lead acid battery but in this module, the main advantage here is that there is no auxiliary power source to support it and it depends solely on the power source which is the solar panel. The solar panel that is used is polycrystalline silicon based that have a maximum voltage V_{max} of 21.6V and a maximum current, I_{max} of 2.44A. As for the module, it is divided into two parts where a constant voltage is needed to be constantly supplied to the battery despite the varying voltage received by the solar panel from the sun. Hence, there are two circuits in the module that is needed to be designed where one will work as a boost converter up to 15V for the input voltage that is lower than 15V while another circuit will work as a voltage regulator where it regulates any input voltage higher than 15V to a constant 15V. The sub-modules will be further explained below before the design of the pulse width modulation solar charger module can be elaborated.

3.4.1 PWM Boost Converter Switching Regulator (LM2578)

In this sub-module, the LM2578 is used to receive any voltage that is below 15V and boost it up to a constant 15V. The LM2578 have an on board oscillator to control the duty cycle up to 90% which sets the frequency with a single external capacitor from 1Hz to 100kHz. Besides that, it operates from supply voltages from 2V to 40V with an output current up to 750mA and has an internal protection circuit such as the current limit and thermal shutdown too.

The circuit for the PWM boost converter is shown below in the figure where it is capable to receive only an input voltage that ranges from 4.5V to 8.5V, giving an output current of 150mA and a constant voltage of 15V.

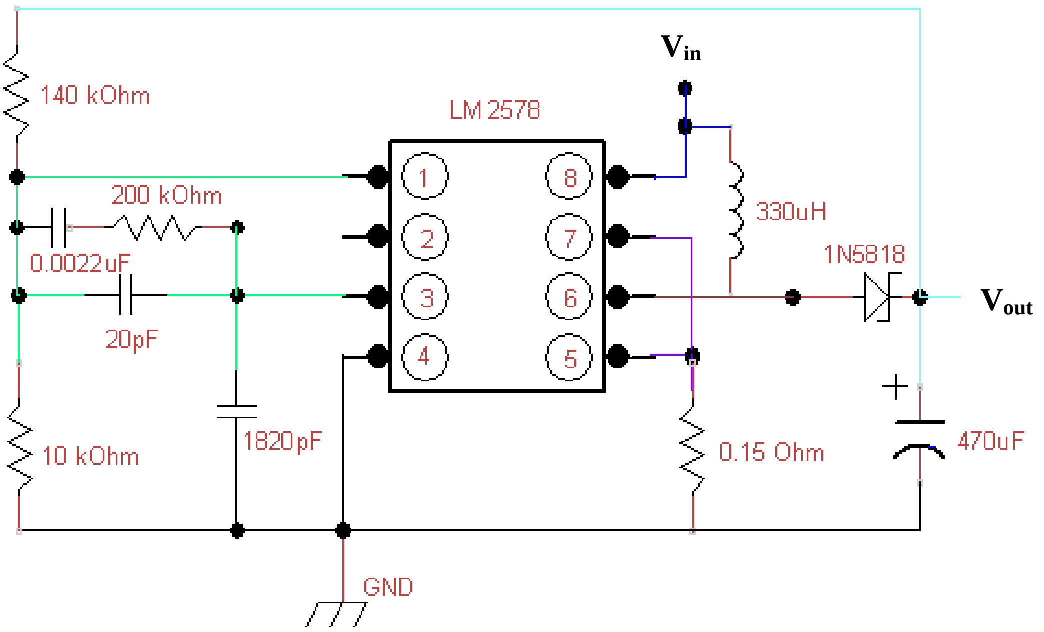


Figure 3—6 : PWM Boost Converter Switching Regulator (LM2578)

3.4.2 Voltage Divider

The voltage divider circuit is designed in this sub-module mainly to accommodate the LM2578 where it helps by receiving the voltage from the solar panel and regulating it down to a smaller voltage to fit the range that is set for the PWM Boost Converter voltage input which is in the range of 4.5 to 8.5. Hence, the voltage divider is the most feasible way to ensure that the input voltage will safely fall in that range.

The resistance value of the voltage divider needs to be determined to ensure that it has the capability to withstand a certain amount of power and also current that flows through it. Hence, the resistance value here plays an important role.

Since the V_{max} = 21.6V and the I_{max} = 2.44A, the maximum power received from the solar panel can be estimated.

$$Maximum\ Power = (Imax)(Vmax)$$

$$= (2.44)(21.6) = 52.7W$$

Hence, the maximum power received from the solar panel, P_{max} = 52.7W. From here, the resistor that is used for the voltage divider is the power resistor. The maximum power that has been determined in this sub-module is P_{max} = 10W where,

$$Maximum\ Power = (Imax)(Vmax)$$

$$10W = (Imax)21.6V$$

$$Imax = 0.4629A$$

From here, the resistance value of the power resistor can be determined.

$$Vmax = (Imax)(R)$$

$$21.6V = (0.4629A)(R)$$

$$R = 46.67\Omega$$

Hence, the figure below shows the configuration of the voltage divider circuit. For example, if the V_{in} is 12V, then the V_{out} will be 6V. Hence it falls in between the range of the voltage input for the LM 2578.

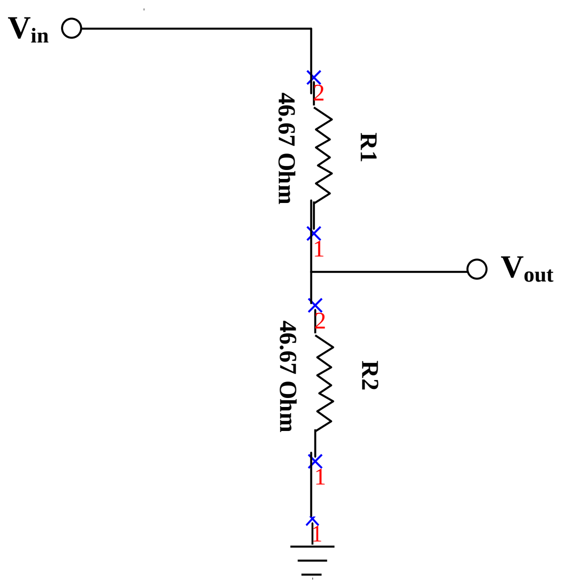


Figure 3—7 : Voltage Divider

3.4.3 Comparator (UA741CN)

Comparator is used in the circuit that receives below 15V to boost it up to a constant 15V where if a voltage reference, V_{ref} is set and the V_{in} is been fed into the circuit is equivalent to the V_{ref} , the comparator will send a 'high' signal output which will give a voltage output of the V_{cc} of the comparator. On the other hand, if the V_{in} does not match the V_{ref} , the comparator will send a 'low' signal output that gives no output voltage. This comparator needs a positive and negative V_{cc} input voltage to function.

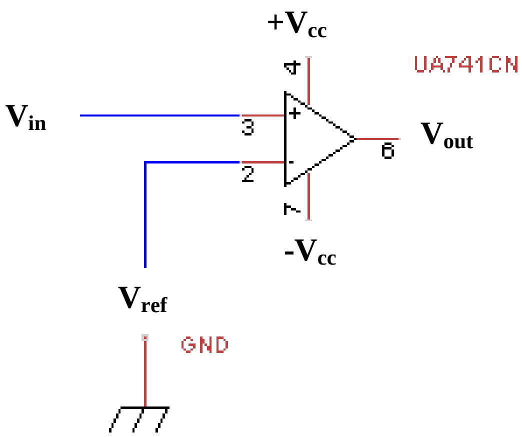


Figure 3—8 : Comparator

3.4.4 CD 4081 CMOS AND Gate

The CD 4081 CMOS AND Gate contains four integrated AND Gate in the 16 legged chip. It is used to combine two output from the comparators where it connects to the AND Gate and the signal output is from the multiplication of both signal input. Besides that, the CD 4081 CMOS AND Gate must be powered up using the V_{dd} and V_{ss}. The formula for the CMOS AND Gate is as shown below with the circuit figure.

$$C = A \cdot B$$

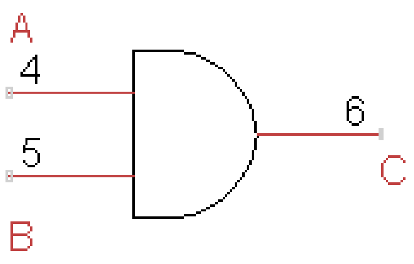


Figure 3—9 : CD 4081 CMOS AND Gate

3.4.5 Negative Voltage ($-V_{cc}$) Supply

A negative voltage ($-V_{cc}$) supply is used to receive a positive input voltage value and converts it into negative voltage value. This is needed to power up the operational amplifier (comparator) and also the CMOS AND Gate. For example, if the V_{in} is 6V, then the V_{out} of the negative voltage supply should be approximately -6V. The negative voltage supply uses a NE555 chip (555 timer) to generate a negative voltage as can be seen in the figure below.

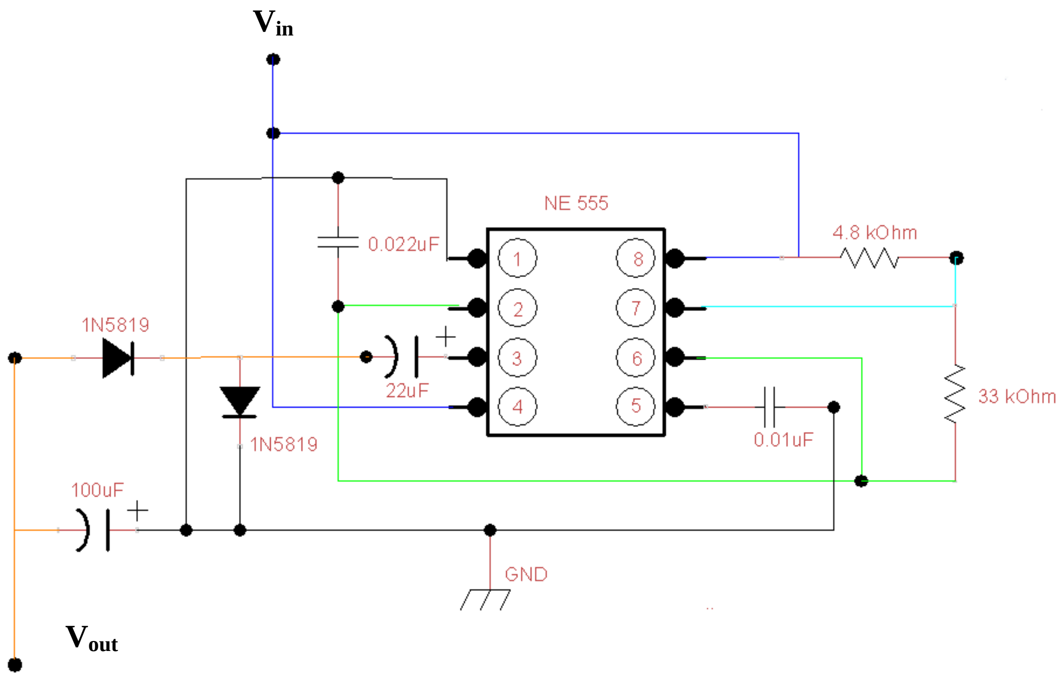


Figure 3—10 : Negative Voltage Supply

<u>Component Marking</u>

1 – GND

2 – Trigger

3 – Output

4 – Reset

5 – Control Voltage

6 – Threshold

7 – Discharge

8 – V_{cc}

3.4.6 Silicon Controlled Rectifier (SCR) Thyristor

The silicon controlled rectifier (SCR) thyristor consists of four layers of differently doped silicon rather than the three layers of the conventional bipolar transistors. This thyristor have a structure of p-n-p-n with the electrodes as the contact known to be anode (n-type) and cathode (p-type). The control terminal of the SCR is known to be the gate and is connected to the p-type layer that joins with the cathode layer. The characteristics of thyristor is different from any other electrical components where if there is usually no current flow across the device but however if a voltage supply is conducted through the device and a small amount of current is supplied to the base of the SCR, it will trigger the base allowing the device to conduct. This state will remain the same until the supply voltage is removed. In other words, it latches once it is turned on until a power source to the SCR thyristor is completely removed. The circuit that is applicable to the PWM Solar Charger is shown in the figure below.

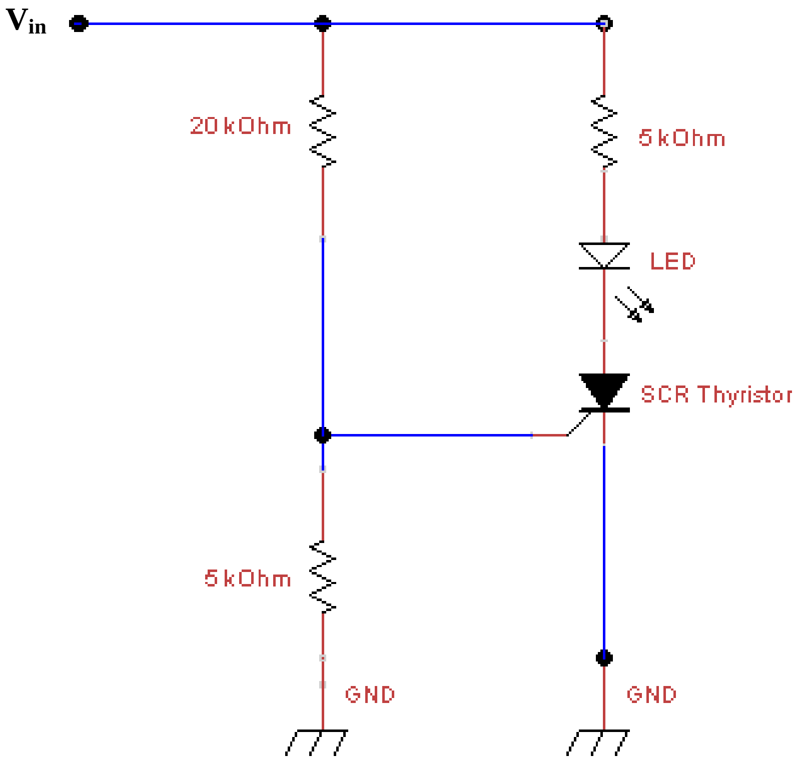
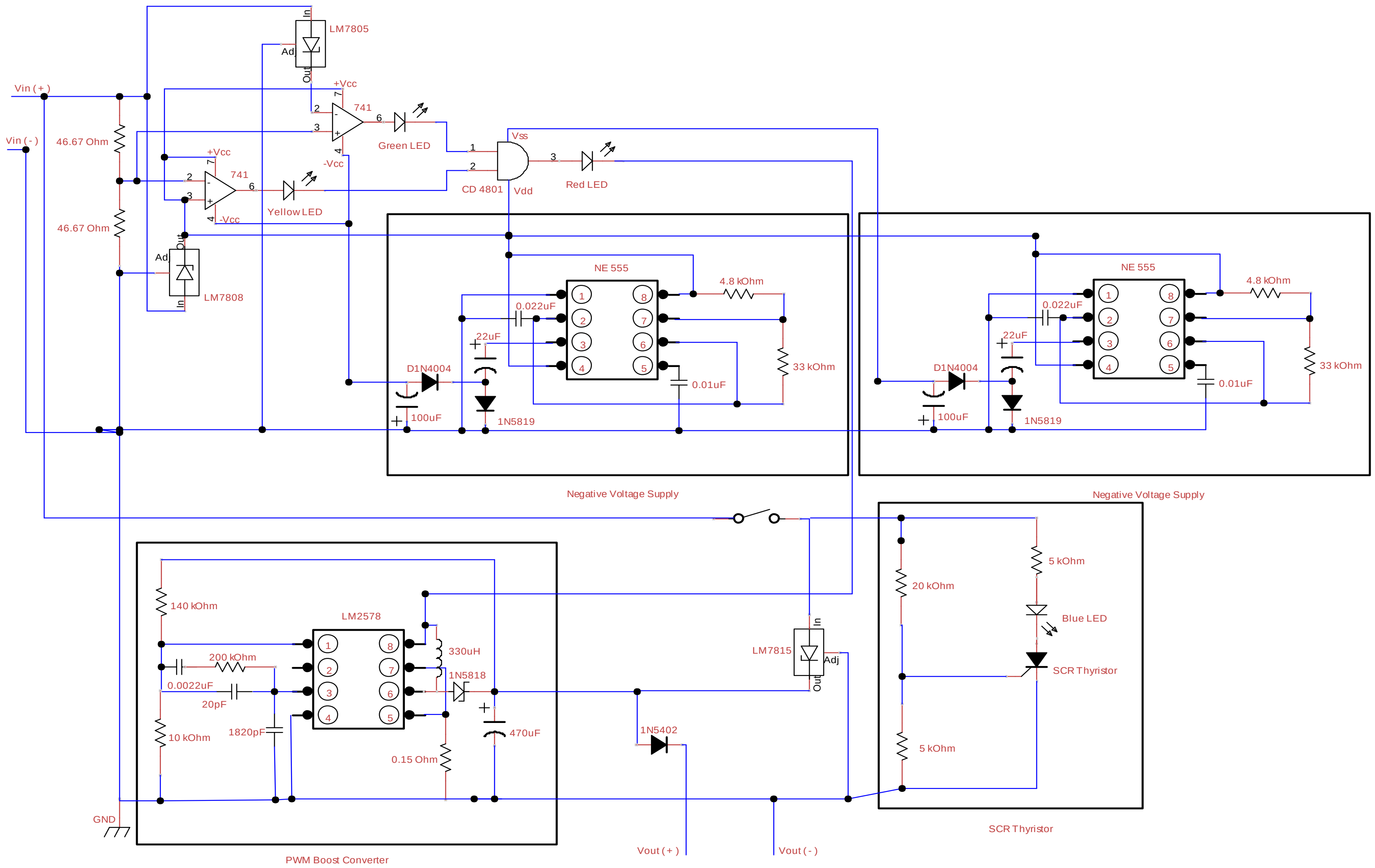


Figure 3—11 : SCR Thyristor

3.4.7 PWM Solar Charger Circuit Design

Most of the sub-modules circuit have been explained earlier; hence when it is all combined into one module, it will be as shown in the figure below.

Figure 3—12 : PWM Solar Charger Circuit



In the module, it is divided into two circuits where one circuit receives any input voltage that is less than 15V and the other receives any input that is above 15V respectively. Looking at the first circuit, the input voltage will be fed into the voltage divider from the solar panel where it sends in half of the voltage value received into both the comparator. The comparator with the yellow LED will turn on, signalling that it receives a high (1) signal if the input voltage received from the voltage divider is below 8V. On the other hand, the comparator with the green LED will turn on, signalling that it receives a high (1) signal when the input voltage received is above 5V. This will create a threshold for the input voltage where both comparators only allow input voltage that ranges from 5V to 8V only to send a high signal to the comparator's output. Any value below or above this threshold will send a low (0) signal to the output of the comparator. The reasoning for creating such threshold is because the input to the LM2578 (PWM Boost Converter) only allows an input voltage that ranges from 4.5V to 8.5V. If the input voltage exceeds 8V, the green LED will still be turned on but the yellow LED will turn off while if the input voltage is below 8V and 5V, the yellow LED will turn on but the green LED will still be off. The V_{ref} in both the comparator is generated through voltage regulators which is LM7805 (5V voltage regulator) for the comparator that turns on if the input voltage is more than 5V and LM7808 (8V voltage regulator) for the comparator that turns on if the input voltage is below 8V. Both voltage regulators tap the voltage from the V_{in} of the module.

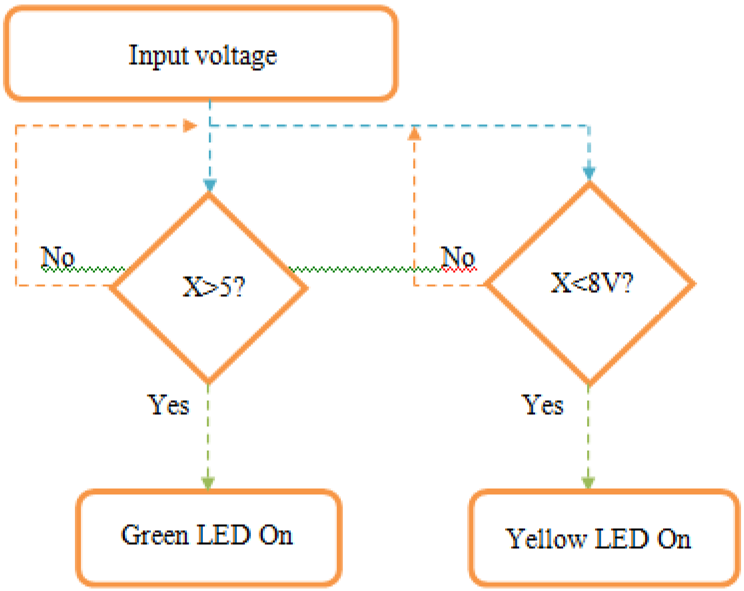


Figure 3—13 : Flowchart Receiving Less than 15V Input

Once the signal goes through both comparators, it will be sent into the CMOS AND Gate where it undergoes multiplication arithmetic. If both signals are high, then the AND Gate will be triggered to have a high (1) output signal which will send an output voltage that is the value of the V_{DD} where the Red LED will turn on. Any other combination of signals received from the comparators will not trigger the AND gate, not allowing any output voltage to be produced, hence turning off the Red LED and sends out a low (0) output signal. Since the V_{DD} is tapped from the LM7808 (8V voltage regulator), hence the output voltage will be approximately 8V which will be the input to the LM 2578 (PWM Boost Converter). This will then boost the PWM solar charger output voltage up to 15V as mentioned in the earlier sub topics. This condition will only work for any voltage that is below 15V and since the voltage is boosted up, this part of the circuit will only manage to output a low current hence this is suitable only for trickle charging of the battery. Since there is no auxiliary battery, the negative voltage circuit will generate negative voltage to the comparators and also the CMOS AND Gate. One negative voltage circuit has the capability to supply 200mA hence the module needs two sets of negative voltage to support the comparator and the CMOS AND Gate.

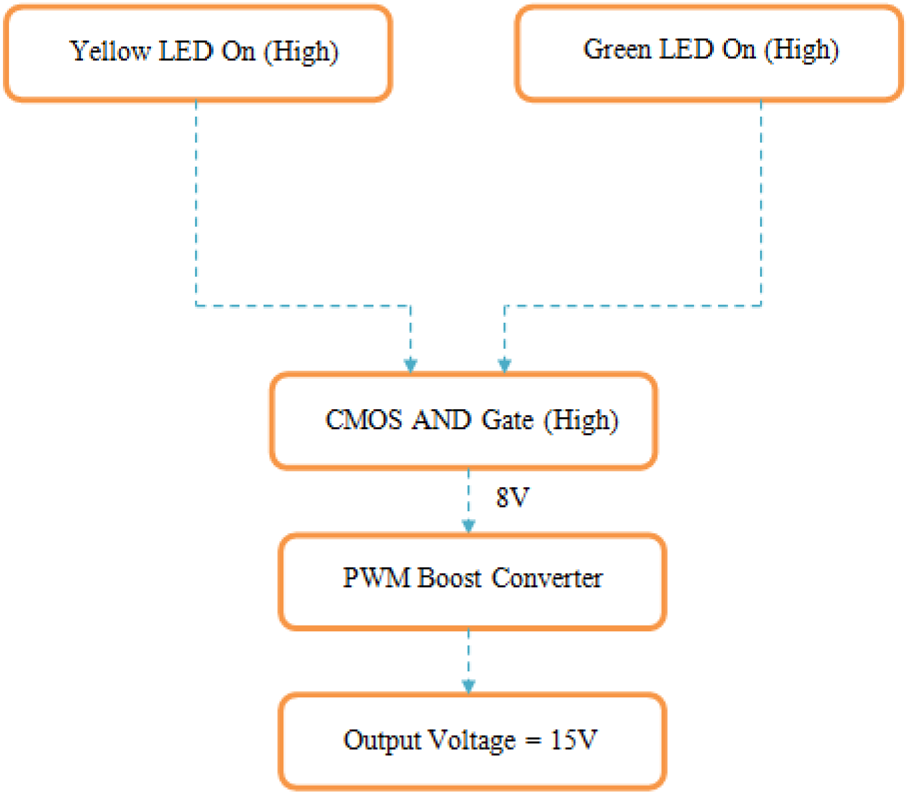


Figure 3—14 : Input below 15V that is fed into the PWM Boost Converter

In the second circuit, for any voltage higher than 15V that is produced by the solar panel, it will undergo voltage regulation through the LM 7815 (15V voltage regulator) circuit. The switch in the module is used to isolate both circuits from each other. As seen in the circuit, the SCR thyristor is needed to turn the blue LED on as an indication that it is working or charging the battery using that circuit. In this case, the output of the PWM solar charger would be 15V.

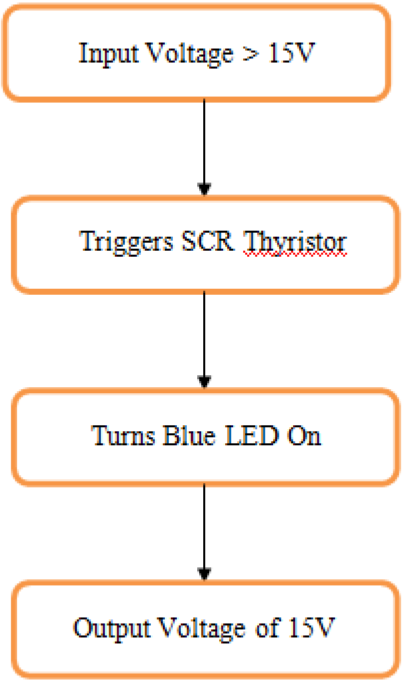


Figure 3—15 : Flowchart Receiving More than 15V Input

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 The Estimation of the State of Charge

The estimation of the state of charge was a success where this module was done from the 22nd of Febuary 2011 until the 10th of March 2011. This module is very important to understand the lifespan and the characteristics of a 12V, 75Ah maintenance free lead acid battery by Tai Kwong-Yokohama Battery Industries Sdn Bhd, under load condition and how it actually works in real life. Hence, it is carried out in a conducive environment with a approximate temperature of 80 Fahrenheit for optimum data reading. The set up followed by the data reading is as shown below.

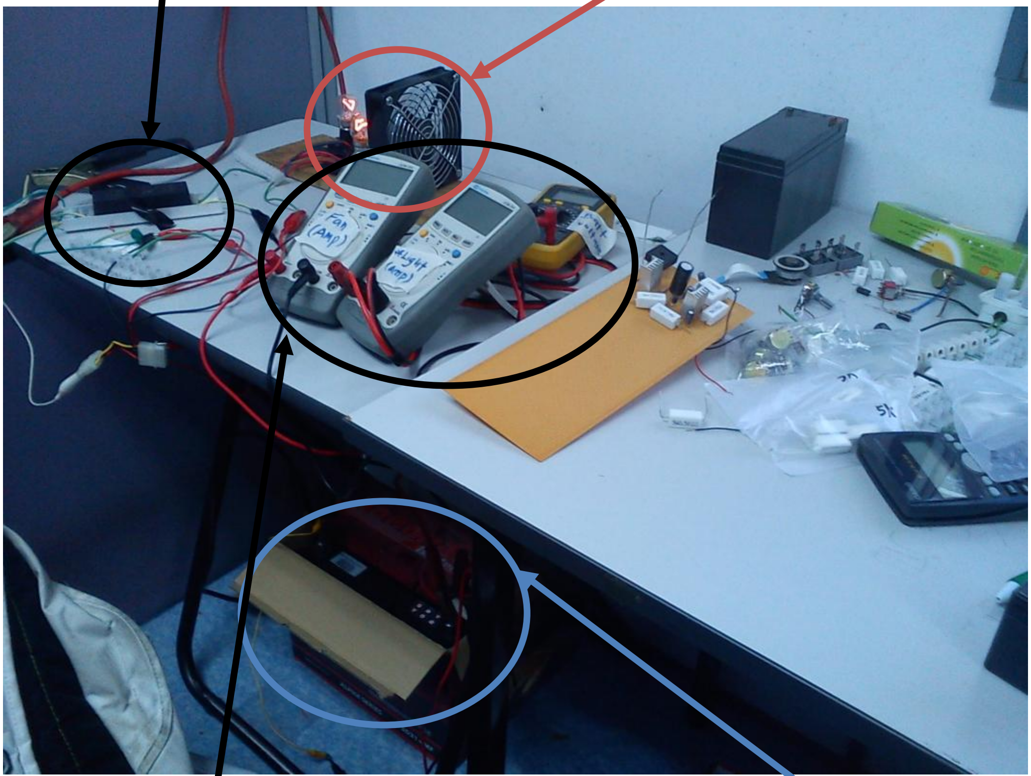


Figure 4—1 : Measuring the SOC

Table 4-1 : SOC Calculation for 12V, 75Ah Lead Acid Battery

Date	Time	Fan (Amps)	AC Light (Amps)	Battery Voltage	SOC Percentage (%)
23/2/2011	12.00pm	0.159	0.069	12.44	73.776
	12.30pm	0.149	0.083	12.36	63.324
	1.00pm	0.149	0.079	12.36	63.324
	2.00pm	0.149	0.079	12.36	63.324
	2.30pm	0.149	0.079	12.38	65.937
	3.00pm	0.148	0.077	12.37	64.6305
	3.30pm	0.148	0.077	12.36	63.324
	4.00pm	0.149	0.075	12.38	65.937
	4.30pm	0.149	0.075	12.38	65.937
	5.00pm	0.15	0.07	12.34	60.711
	5.30pm	0.15	0.07	12.34	60.711
23/2/2011	10.10am	0.15	0.071	12.37	64.6305
	10.40am	0.15	0.071	12.37	64.6305
	11.10am	0.149	0.07	12.33	59.4045
	11.40am	0.149	0.072	12.33	59.4045
	12.10pm	0.149	0.072	12.32	58.098
	12.40pm	0.148	0.074	12.32	58.098
	1.10pm	0.147	0.076	12.32	58.098
	3.30pm	0.148	0.073	12.32	58.098
	4.00pm	0.148	0.073	12.32	58.098

	4.30pm	0.149	0.065	12.3	55.485
	5.00pm	0.147	0.065	12.3	55.485
	5.30pm	0.149	0.064	12.3	55.485
	6.00pm	0.149	0.063	12.29	54.1785
24/2/2011	10.30am	0.149	0.06	12.29	54.1785
	11.00am	0.149	0.06	12.29	54.1785
	11.30am	0.148	0.061	12.28	52.872
	12.00pm	0.147	0.062	12.28	52.872
	12.30pm	0.146	0.063	12.28	52.872
	1.00pm	0.145	0.064	12.27	51.5655
	1.30pm	0.145	0.065	12.27	51.5655
	2.00pm	0.147	0.065	12.27	51.5655
25/2/2011	10.45am	0.146	0.068	12.26	50.259
	11.15am	0.145	0.069	12.26	50.259
	11.45am	0.145	0.07	12.25	48.9525
	1.30pm	0.148	0.065	12.25	48.9525
	2.00pm	0.148	0.065	12.25	48.9525
	2.30pm	0.148	0.064	12.24	47.646
	3.00pm	0.147	0.064	12.24	47.646
	3.30pm	0.146	0.065	12.24	47.646
28/2/2011	11.00am	0.144	0.066	12.22	45.033
	12.00pm	0.144	0.066	12.22	45.033
	1.30pm	0.144	0.066	12.22	45.033

	2.30pm	0.142	0.067	12.22	45.033
	3.30pm	0.143	0.066	12.21	43.7265
	4.30pm	0.143	0.065	12.2	42.42
	5.30pm	0.144	0.065	12.2	42.42
	6pm	0.144	0.065	12.19	41.1135
29/2/2011	10.00am	0.145	0.064	12.19	41.1135
	11.30am	0.143	0.065	12.18	39.807
	4.30pm	0.145	0.063	12.17	38.5005
	5.30pm	0.145	0.063	12.17	38.5005
	6.30pm	0.145	0.063	12.16	37.194
	7.30pm	0.144	0.063	12.15	35.8875
2/3/2011	3.30pm	0.143	0.063	12.14	34.581
	4.30pm	0.143	0.063	12.14	34.581
	5.30pm	0.143	0.062	12.14	34.581
	6.30pm	0.144	0.061	12.12	31.968
	7.30pm	0.143	0.06	12.11	30.6615
3/3/2011	12.30pm	0.143	0.064	12.12	31.968
	1.30pm	0.143	0.064	12.12	31.968
	2.30pm	0.143	0.062	12.11	30.6615
	3.30pm	0.144	0.061	12.1	29.355
	4.30pm	0.145	0.06	12.09	28.0485
	5.30pm	0.141	0.071	12.08	26.742
4/3/2011	11.30am	0.14	0.064	12.06	24.129

	2.00pm	0.14	0.064	12.06	24.129
	2.30pm	0.141	0.064	12.06	24.129
7/3/2011	10.30am	0.141	0.065	12.05	22.8225
	11.30am	0.141	0.065	12.05	22.8225
	12.30pm	0.14	0.064	12.05	22.8225
	2.30pm	0.142	0.06	12.03	20.2095
	3.30pm	0.142	0.064	12.03	20.2095
	4.30pm	0.142	0.062	12.02	18.903
	5.30pm	0.142	0.062	12	16.29
	6.30pm	0.142	0.062	12.01	17.5965
	9.00pm	0.142	0.062	11.99	14.9835
	10pm	0.141	0.063	11.97	12.3705
9/3/2011	2.30pm	0.141	0.064	11.98	13.677
	3.30pm	0.141	0.064	11.98	13.677
	4.30pm	0.141	0.063	11.98	13.677
	6.30pm	0.139	0.064	11.95	9.7575
10/3/2011	11.00am	0.14	0.065	11.94	8.451
	12.00pm	0.14	0.065	11.94	8.451
	1.30pm	0.14	0.064	11.93	7.1445
	2.30pm	0.14	0.064	11.92	5.838
	5.00pm	0.14	0.063	11.9	3.225

* short period of break

As seen in the table above, this module approximates the SOC based solely on the voltage drop across the battery only. In ideal cases, it is known that every battery have a SOC that is 100% but in reality, most batteries don’t have an ideal SOC of 100% due to the surrounding temperature, shelf life decrement and toxic chemical leakage that might occur over a period of time. Initially, the data reading is taken for every 30 minute but as this module continues longer over time, the period time of 30 minutes for every data reading is too short of a time to be affected by the SOC. Hence, as the battery hits a certain percentage of SOC for example 50% approximately, a period of 1 hour (60 minutes) is given for every data reading from there on. In the figure below, the graph of battery voltage vs the state of charge is plotted.

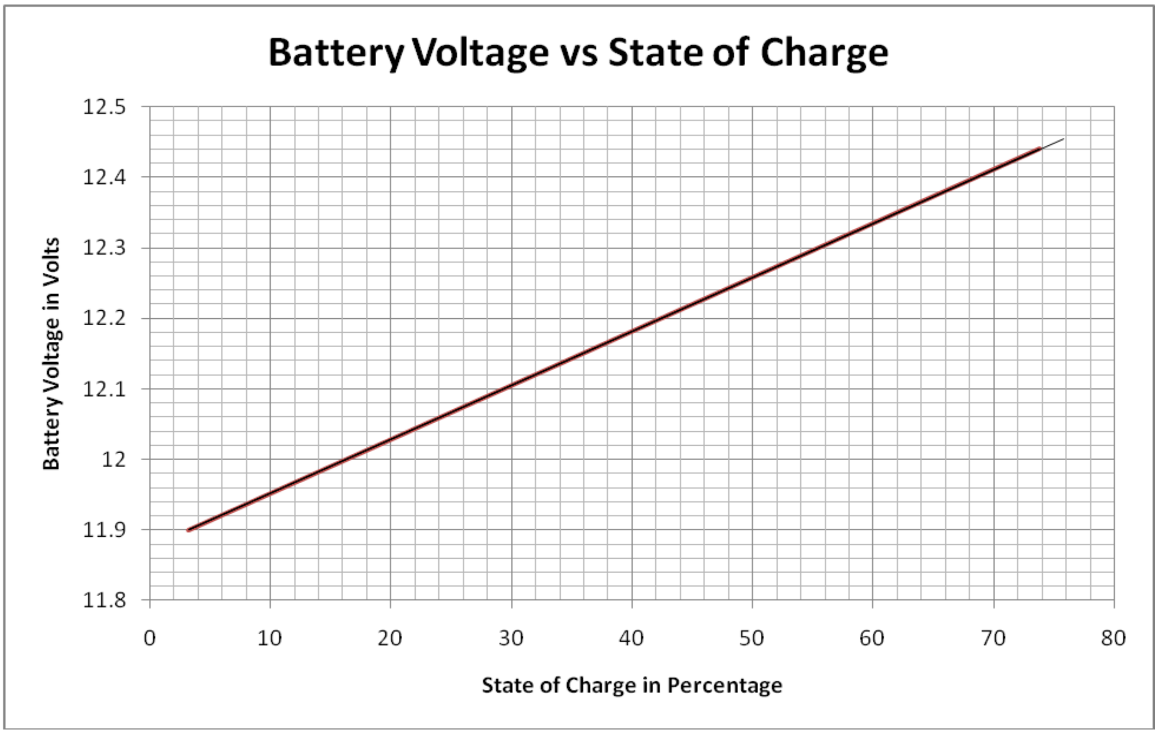


Figure 4—2 : Battery Voltage vs SOC in Percentage

As seen in the figure above, there is a linear drop of SOC as the battery discharges. This is just an ideal case where the load condition remains constant which it is the simulation of anything else other than the battery management system such as the car headlights, horn, wiper, air conditioning and any other constant load that is in the car. On the other hand, it has been tested that the battery management system or known also as EVICS (Electric Vehicle Intelligence Control System) can be powered using 12V, 75Ah maintenance free lead acid battery for a period of approximately 12 hours using an inverter to convert the battery source of DC into 3 phase AC power. At certain voltage, it is observed that there is a drop in the SOC percentage and then it increases again as can be seen for example at V=12.36 and V=12.38. This occurs due to two factors where first, the calculation method as mentioned earlier is not as accurate as the hydrometer hence there might be a small variation with the SOC percentage in the calculation and the second factor is that it is because when the reading is taken, the voltage wasn't given time for it to set in order to obtain a more accurate data reading. This module can be further clarified and justified in appendix that is obtained from the internet where it matches approximately the SOC percentage based on the battery voltage.

Besides that, the SOC of both the 12V with 1.2Ah and 7Ah is also calculated and the table can be seen as follows.

Table 4-2: SOC Calculation for 12V, 1.2Ah Lead Acid Battery

Time	Current	Voltage	SOC Calculation (%)
1.25pm	1.84	12.49	80.3085
1.30pm	1.75	12.29	54.1785
1.35pm	1.65	12.2	42.42
1.40pm	1.6	12.02	18.903
1.45pm	1.56	11.93	7.1445
1.50pm	1.45	11.89	1.9185
1.55pm	1.42	11.89	1.9185

Table 4-3: SOC Calculation of 12V, 7Ah Lead Acid Battery

Time	Current	Voltage	SOC Calculation
3.00pm	1.82	12.43	72.4695
3.15pm	1.73	12.3	55.485
3.30pm	1.69	12.24	47.646
3.45pm	1.62	12.21	43.7265
4.00pm	1.52	12.17	38.5005
4.15pm	1.4	12.13	33.2745

4.30pm	1.42	12.09	28.0485
5.00pm	1.43	12.03	20.2095
5.15pm	1.4	12.01	17.5965
5.30pm	1.35	11.98	13.677
5.45pm	1.31	11.92	5.838
6.00pm	1.29	11.9	3.225

4.2 Lead Acid Battery Charger

This module is designed to charge up the 12V, 1.2Ah lead acid battery and also the 12V, 7Ah lead acid battery. The set up and the circuit design can be seen in the figure below.

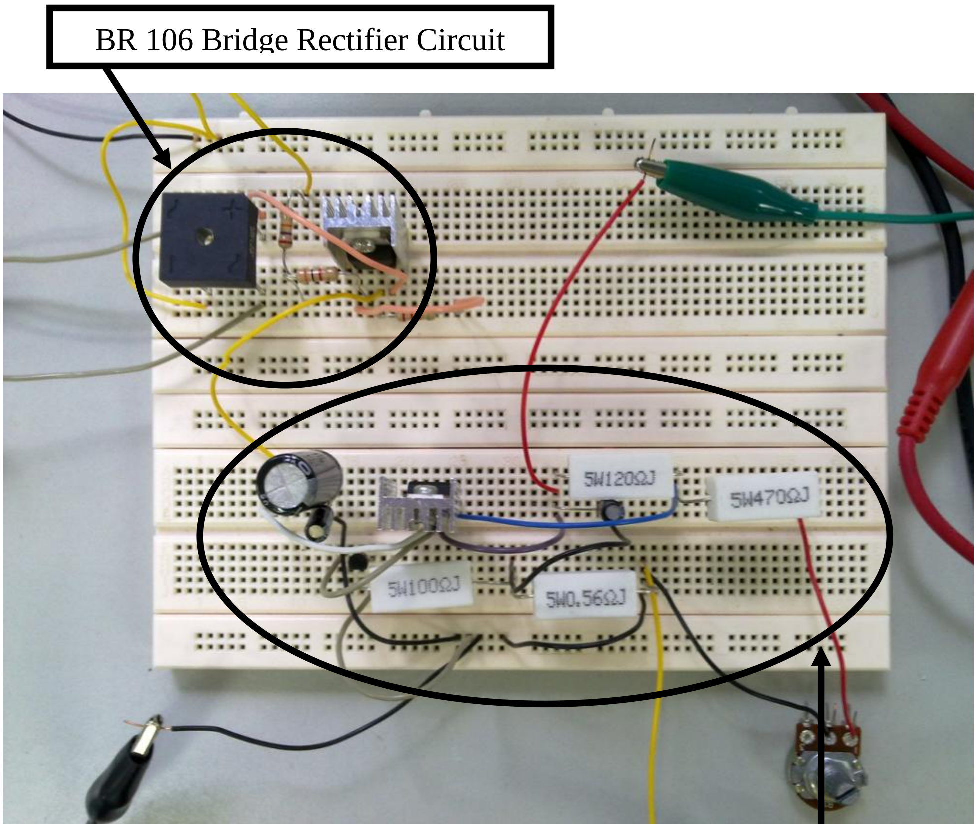


Figure 4—3 : Lead Acid Battery Charger

Once it has been integrated into the board, the set up looks like as shown below.

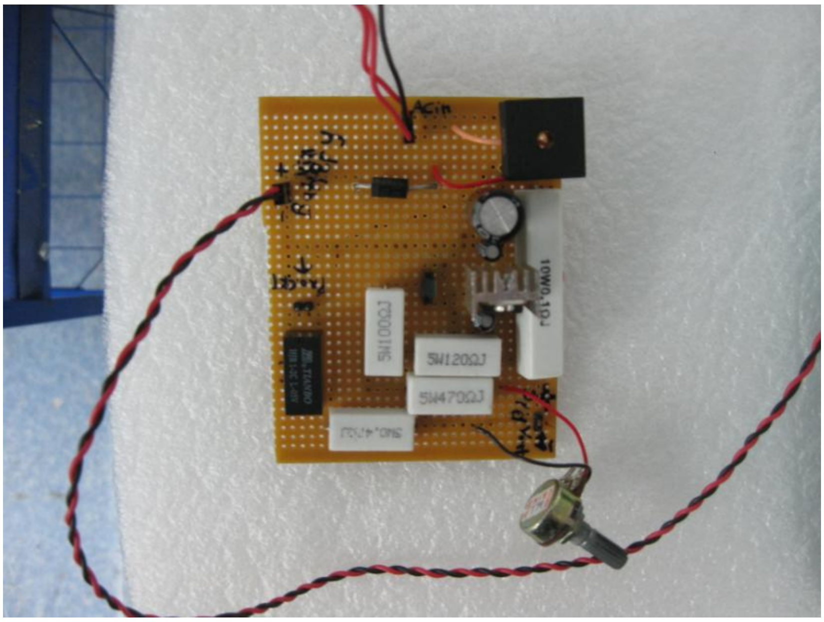


Figure 4—4 : Integrated Lead Acid Battery Charger

This lead acid battery uses the constant-voltage-constant-current method as mentioned and this charging circuit cannot be used for the 12V, 75Ah rated lead acid battery as the LM317 is only able to provide an output current up to 1.5A only. The relay in the circuit is meant for protection if it short circuits, overvoltage or overcurrent happens. The 75Ah rated battery can be charged only if there is a current booster circuit in it which is also very costly and due to budget constraints, the charging of the 12V, 75Ah battery cannot be completed. Hence, this charging profile will be based on the 1.2Ah and 7Ah lead acid battery. The data obtained from this charging circuit can be seen in the table below.

Table 4-4: Charging of 12V, 1.2Ah Lead Acid Battery

Time	Voltage	Current
3.00pm	11.87	0.22
3.30pm	12.48	0.22
4.00pm	12.85	0.23
4.15pm	13.03	0.24
4.30pm	13.14	0.23
4.45pm	13.26	0.22
5.00pm	13.46	0.23
5.15pm	13.68	0.23
5.30pm	13.87	0.24
5.45pm	14.25	0.19
6.00pm	14.34	0.15
6.15pm	14.4	0.11
6.30pm	14.42	0.09
6.45pm	14.44	0.07
7.00pm	14.45	0.06
7.15pm	14.47	0.05
7.30pm	14.45	0.05
7.45pm	14.47	0.05
8.00pm	14.48	0.05
8.15pm	14.48	0.04
8.30pm	14.48	0.04

The set up for this charging circuit can be seen in the figure below.

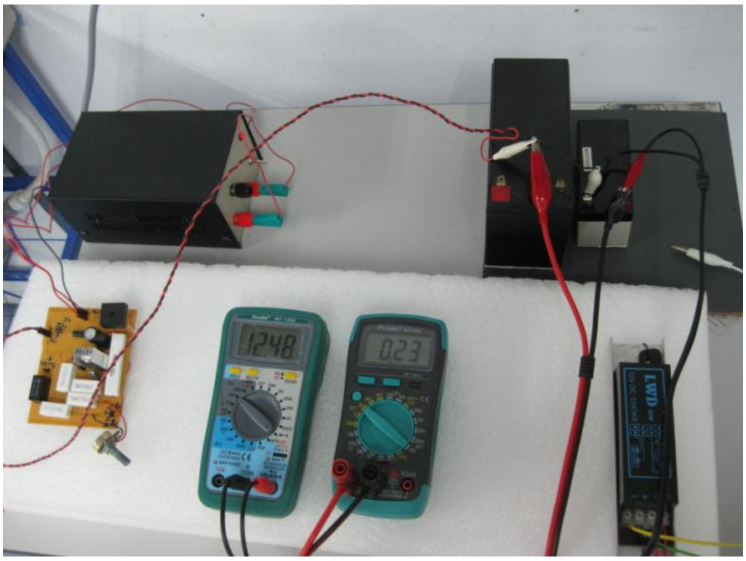


Figure 4—5 : Battery Charging Set Up for 12V,1.2Ah

As can be seen in the table, the characteristics of a constant-voltage-constant-current method can be seen where at first; the voltage is first set at 14.88V and the battery initial voltage after discharging is 11.87. When the charging circuit is connected to the lead acid battery, the voltage increases dramatically to 12.48V. This happens because the lead acid battery has a lower voltage compared to the voltage output from the charging circuit. Hence the multimeter reads the higher voltage value instead of the lower voltage value. As the voltage increases, the current remains constant at the range of 0.24A to 0.22A. After 2 hours and 45 minutes, the voltage starts to stay constant and the output current starts to decrease slowly. When this phenomenon happens, the reading shows us that the battery is approximately 80% charged and it starts to go into the trickle charging phase. After 5 ½ hours, it can be concluded that the lead acid battery is completely charged as the current drops to almost zero. In the figures below, it is shown the state of the battery before and after charging.

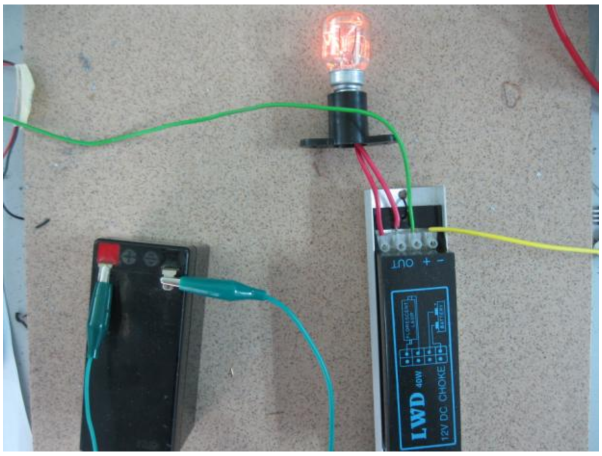


Figure 4—6 : Before Charging the 1.2Ah Battery

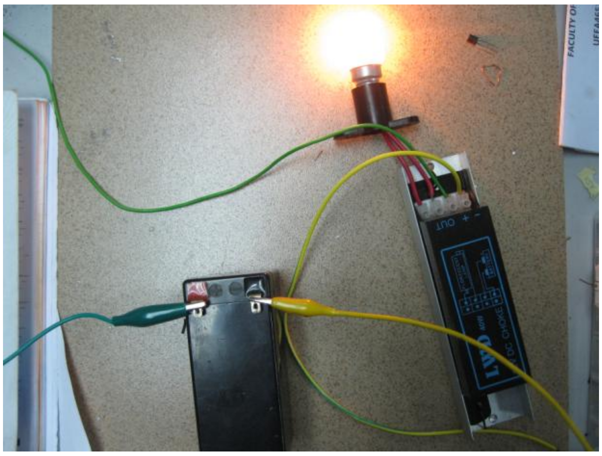


Figure 4—7 : After Charging the 1.2Ah Battery

The pattern of constant-voltage-constant-current method can be visualized easier in the graph below in the figure.

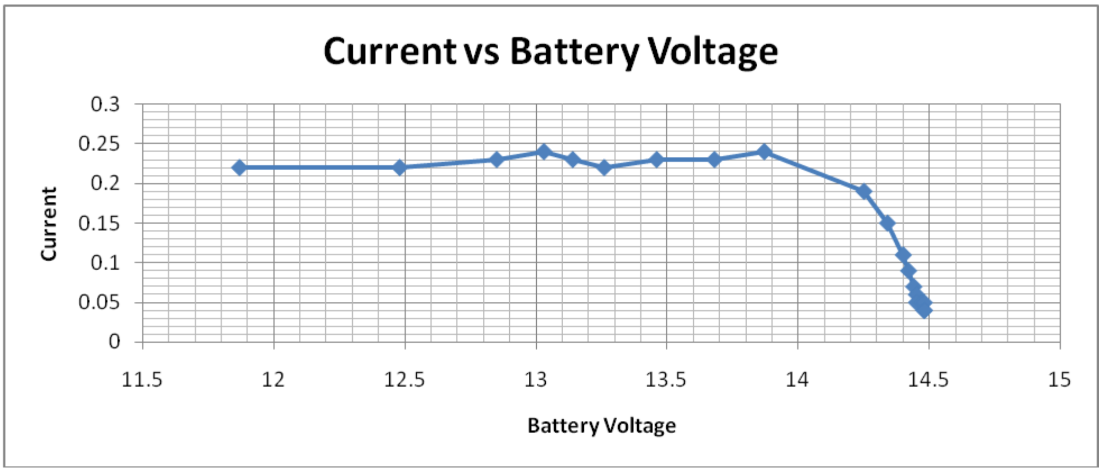


Figure 4—8 : Current vs Battery Voltage (1.2Ah)

The data reading for the 12V, 7Ah lead acid battery is as shown below.

Table 4-5: Charging of 12V,7Ah Lead Acid Battery

Time	Voltage	Current
3.00pm	11.8	0.71
3.30pm	12.35	0.69
4.00pm	12.46	0.68
4.30pm	12.5	0.69
5.00pm	12.56	0.7
5.30pm	12.89	0.68
6.00pm	12.94	0.7

6.30pm	13.12	0.69
7.00pm	13.25	0.69
7.30pm	13.49	0.67
8.00pm	13.62	0.61
8.30pm	13.82	0.52
9.00pm	13.97	0.34
9.30pm	14.1	0.23
10.00pm	14.23	0.11
10.30pm	14.36	0.08
11.00pm	14.38	0.08
11.30pm	14.45	0.06
12.00am	14.47	0.05
12.30am	14.47	0.04
1.00am	14.48	0.04

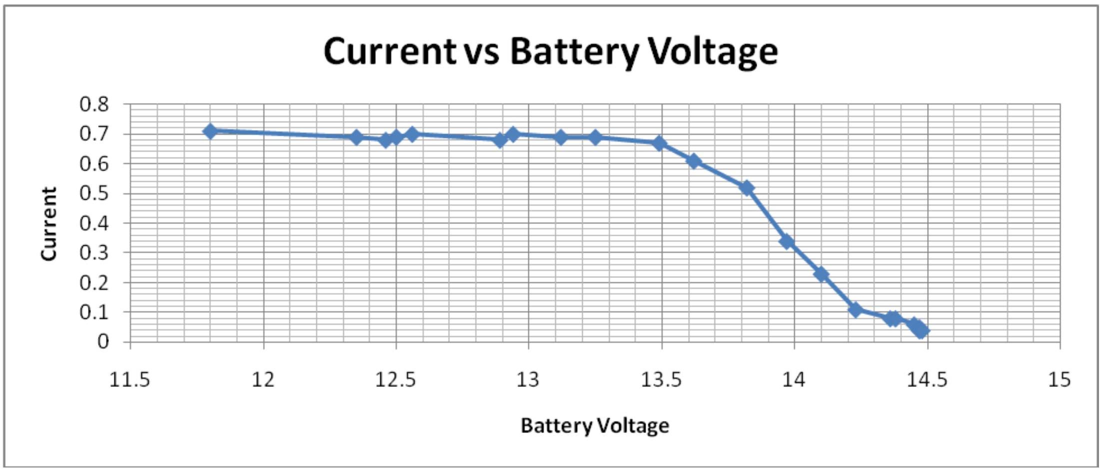


Figure 4—9 : Current vs Battery Voltage (7Ah)

4.3 PWM Solar Charger for Lead Acid Battery

The PWM Solar Charger is one of the highlights in this thesis where it has the capability to use only the solar panel to power up the circuit and simultaneously supplying an output voltage of 15V to the lead acid battery. The set up and the circuit design can be seen in the figure below.

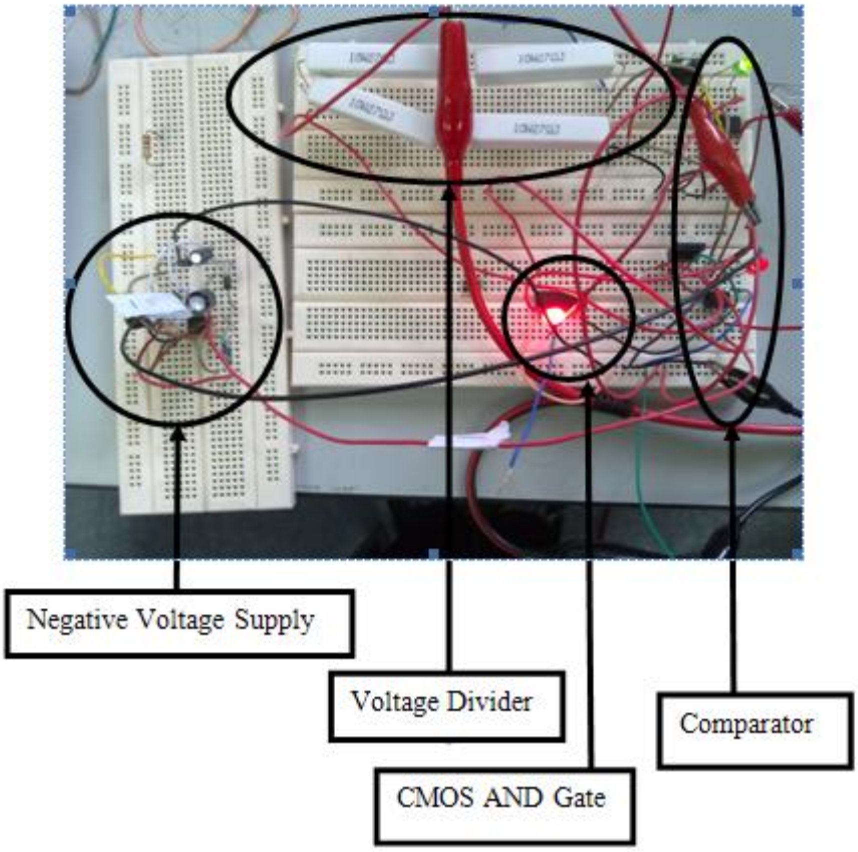


Figure 4—10 : Circuit receiving below 15V with AND Gate

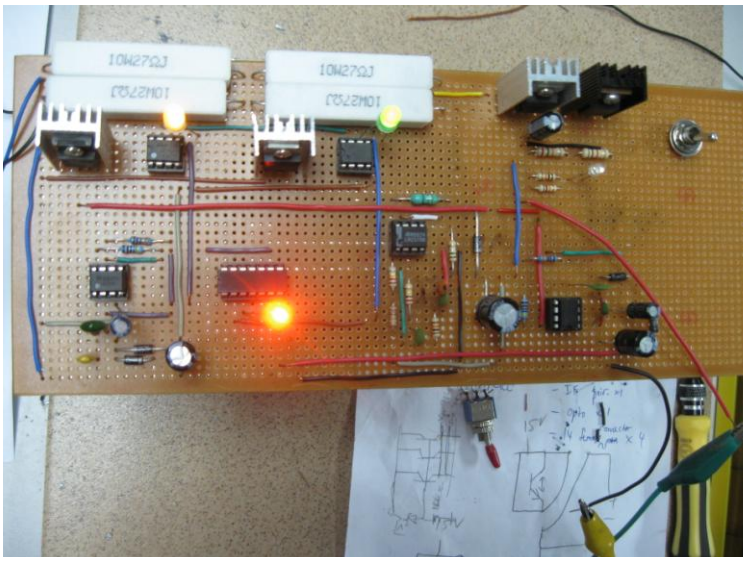


Figure 4—11: When Both Comparator is High, Output at AND Gate is High

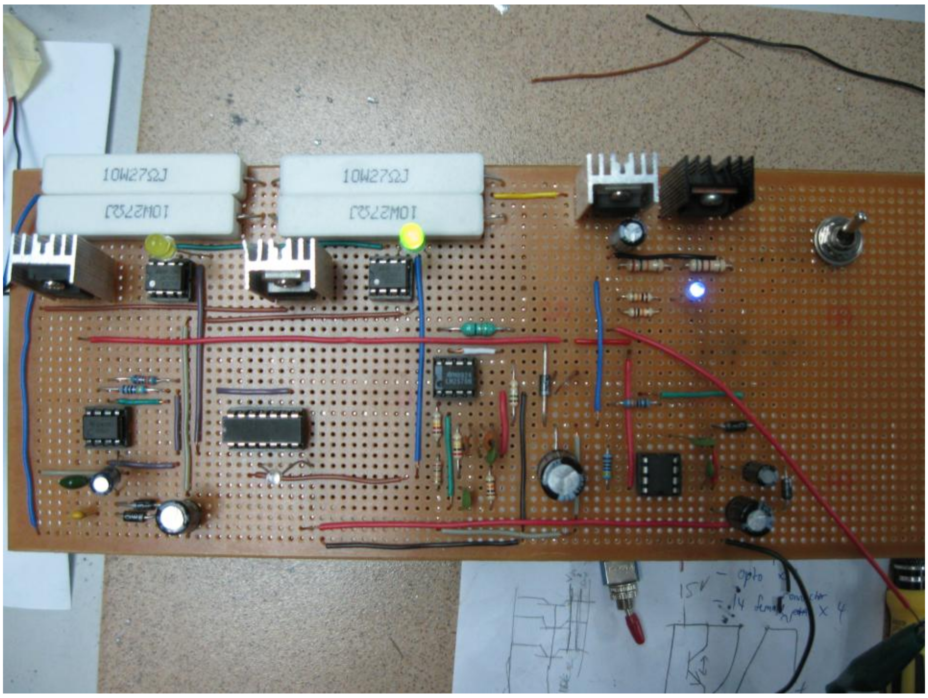


Figure 4—12 : Circuit receiving above 15V as Input Voltage

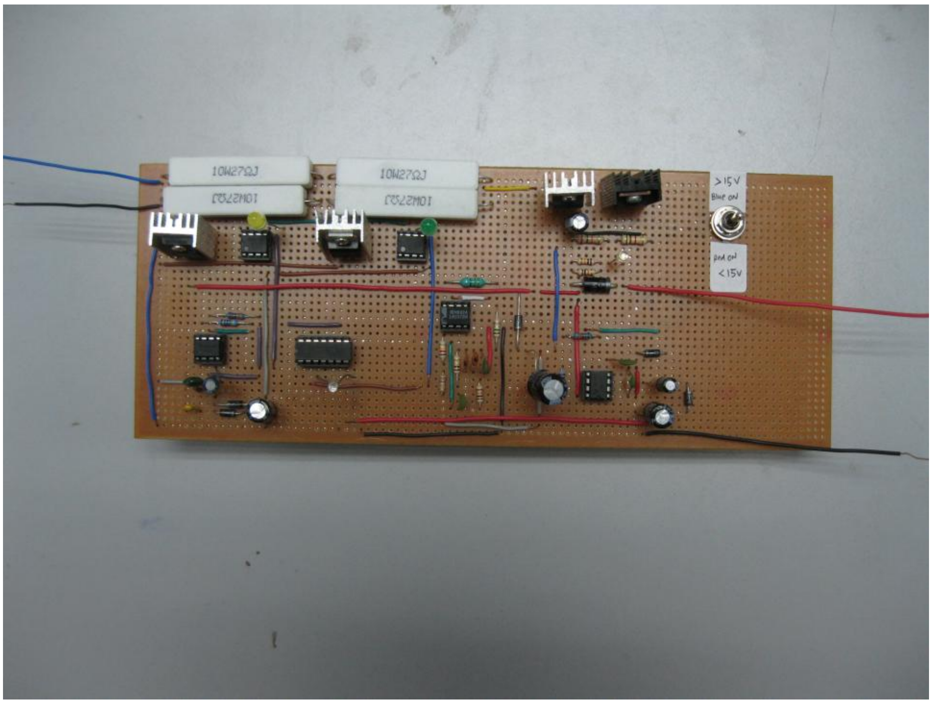


Figure 4—13 : PWM Solar Charger Circuit

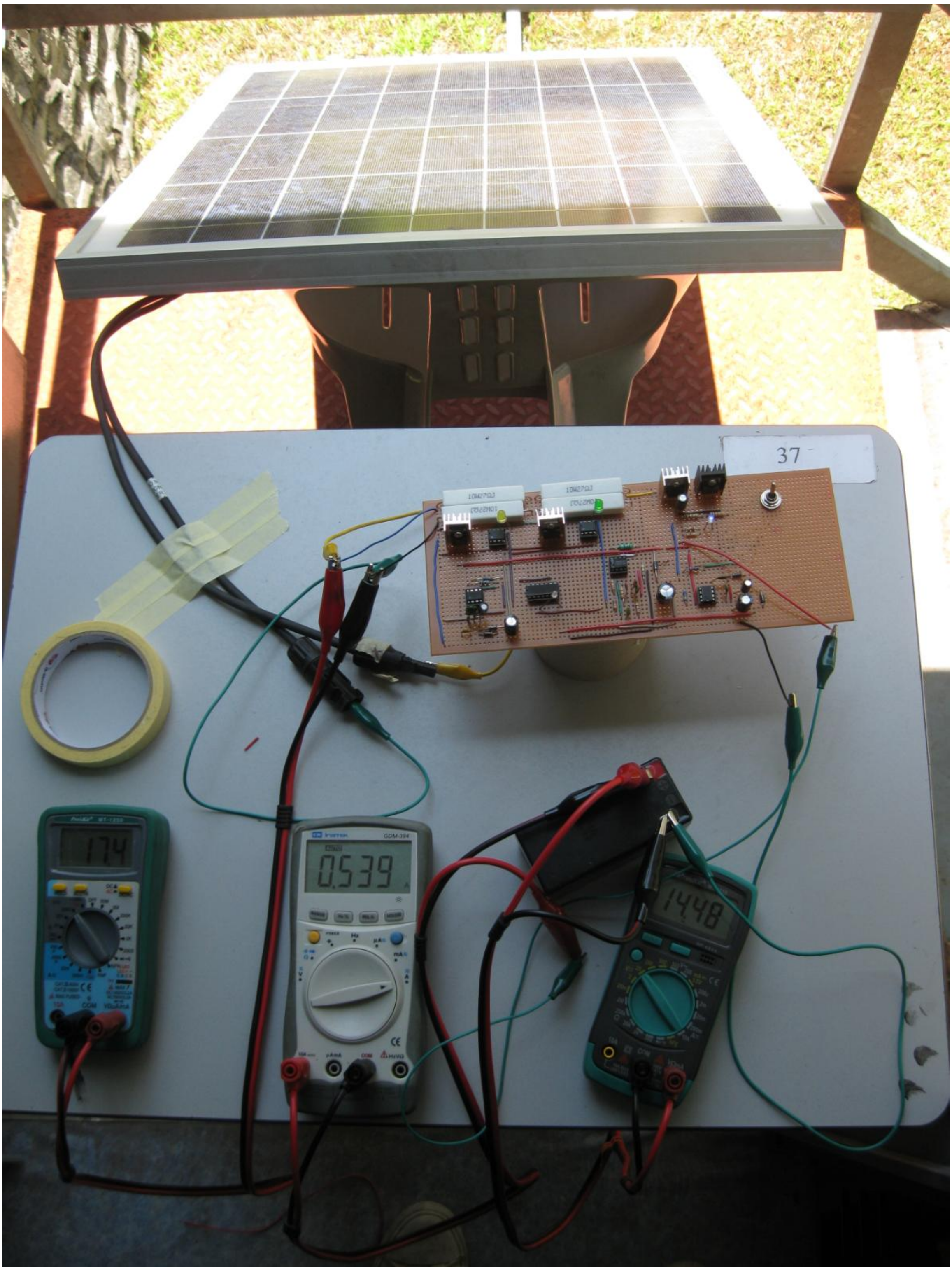


Figure 4—14 : Output Voltage of 14.48V , Blue LED turn On

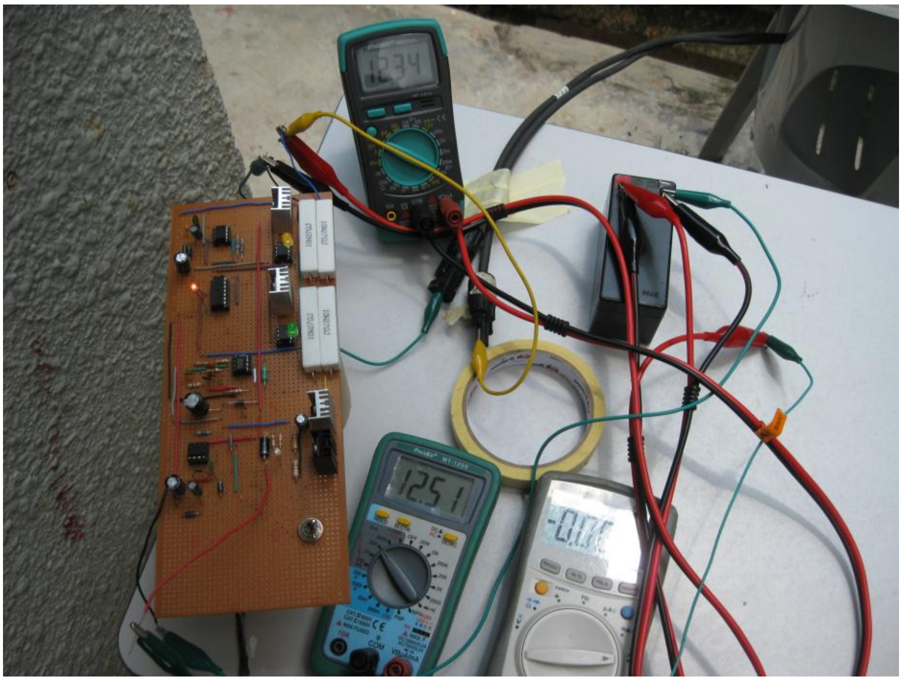


Figure 4—15 : Output Voltage of 12.5V, Red LED turns On

During the testing of this module, the output voltage for the circuit that receives any input below 15V will be 13.6V while the output voltage for the circuit that receives any input above 15V will be 14.4V. This differs from the ideal case where it is supposed to have an output voltage of 15V from both circuits but it is not possible to be so accurate. To summarize the solar charger’s performance, when the weather is cloudy and there’s not much sun, it will go into the trickle charging mode while if there is good weather with a bright sun, it will be in the usual charging mode. The data reading of the PWM Solar Charger can be seen in the table below.

Table 4-6 : Solar Charging on 12V, 1.2Ah Lead Acid Battery

Time	Vsolar	Vout	Iout	Weather
1.45pm	18.21	14.42	0.486	Bright
2.15pm	13.6	13.83	0.457	Slightly Bright
2.45pm	8.3	11.82	0	Cloudy
3.15pm	18.11	14.38	0.481	Bright
3.45pm	6.19	12.14	0	Cloudy
4.15pm	4.27	12.1	0	Cloudy
4.45pm	19.72	14.41	0.491	Bright
5.15pm	13.93	13.76	0.411	Slightly Bright
5.45pm	4.96	12.57	0	Cloudy

6.15pm	4.52	12.52	0	Cloudy
6.45pm	4.32	12.49	0	Cloudy
7.15pm	4.56	12.51	0	Cloudy

As seen in the table above, there is a constant variation received from the solar panel due to the brightness of the sun and how much the solar panel can absorb. And as observed, when the current, I_{out} is zero, means that the circuit is not charging the battery at all because of low voltage and current hence, the circuit is not capable of powering up. Hence the multimeter will show the reading of the battery voltage instead. On the other hand, when the voltage received is at maximum from the solar panel, there is a high voltage input to the circuit giving an almost constant output of approximately 14V-15V hence it will charge the lead acid battery.

This module on the other hand, have a few disadvantages where in ideal cases, two negative voltage supply should be enough to help power up the comparator and the AND Gate but instead it wasn't. Using only two negative voltage supply, it is observed that there is not enough current to help boost the voltage up to 13.6V for the circuit that receives any input voltage below 15V where it only gives an output of 7.6V due to the current that is sharing with the LED's. Hence, using the CD 4081 CMOS AND Gate that have 4 integrated AND Gates, all of the inputs to the AND Gate is connected in parallel with both the comparator's output sending out 4 outputs signals, consisting of a voltage of V_{DD} and a higher total current into the PWM Boost Converter circuit. This will help to boost up the voltage with a higher total current. Since a lot of current is needed to be sent out to the PWM Boost Converter circuit, hence another negative voltage supply is needed to be designed in order to supply enough V_{SS} for the CMOS AND Gate to power up 4 AND Gates too.

Another problem faced by this module is, since there is two circuits that is combined into one module, one circuit must be isolated if the other is turned on. If the circuit is not isolated, then the other circuit draws current hence reducing the output voltage. Give example, if circuit A is turned on, and circuit B is isolated, the output voltage will be 15V but if circuit A and B is turned on and not isolated from each other, the output voltage will be 7.6V due to the lack of current as it shares the current with both circuits. This happens due to the absence of auxiliary battery which is not wanted in this module. Hence, there must be a switching isolating device to isolate circuit A if circuit B is turned on. In this module, a few electrical components have been tested to be this switching isolation device but it wasn’t successful.

For example, a comparator cannot be used again because if another negative voltage supply is designed and all of the negative voltage supply is tapping from the 8V voltage regulator output (LM7808), the output of the latest negative voltage supply circuit will give a low output current due to 3 negative voltages sharing the same current which will be very ‘heavy’ on the LM7808.

A relay also cannot be used in this case due to its magnetization. If circuit A (receives below 15V input voltage) and circuit B(receives above 15V input voltage) is connected to a relay, it will work perfectly if the input voltage is tweaked from below 15V to above 15V where the relay will isolate circuit A and B respectively but if the voltage is lowered from above 15V to below 15V, the relay will latch, hence it still isolates circuit A from circuit B until it reaches a very low voltage (3V) before it switches back, isolating circuit B from circuit A. This latching problem is the main concern here where it doesn’t switch immediately once it goes below 15V. Indirectly this cancels out SCR thyristor too as it latches once it reaches a certain voltage. Hence, a manual switch is used instead to isolate the circuits from each other due to lack of options.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In overall, this project was carried out smoothly and with success. From this project, the characteristics of a maintenance free lead acid battery is investigated and understood. This will provide a basic foundation of understanding for those that would want to go deeper into the battery profile or fast charging profile.

To conclude, there are a few advantages in using a lead acid battery as a power source for an electric vehicle where it does not produce any air pollution and vehicle that are petrol based can be reduced. Besides that, if the battery is low on battery water, it can be purchased at any mechanic shop nearby. Charging stations would also be much more convenient as there are not petrol involved but just electricity. This would help to save cost on oil digging and also electricity cost cheaper than petrol.

On the other hand, there are also a few disadvantages in using a lead acid battery where it is heavy and bulky, taking up a lot of space and weight. And there might be some leakage due to the gas produced by the electrochemical process that takes place in the battery. The lifespan and SOC for one battery considering the amount of load it must support is theoretically short, hence many lead acid batteries is needed in order for the electric vehicle to run at optimum speed and distance. This is very inconvenient for users as often recharging is needed which are a waste of time and effort.

To complete this project, persistence and a willing heart to learn is needed to complete the project. A lot of self development such as reading and understanding has to be done. The most important skills needed to overcome problems and obstacles that comes in the way is troubleshooting and analyzing skills where it is needed to analyze the problem and know how to troubleshoot the problem. Without this two crucial skills needed, it will be difficult to complete this project. Time and budget organization is also important where without organizing, the project deadlines couldn't be met.

5.2 Recommendations

There are a few recommendations that can be done to further improve the performance of the lead acid battery and understand deeper in concept of a lead acid battery.

One of the recommendations that can be implemented is by calculating the state of charge using the Extended Kalman Filtering where the basic idea originates from the Kalman filter. The Kalman filter purpose is to use measurements observed over time that contains inaccuracies, producing values that is closer to the true values of the measurements and their associated calculated value. Basically it true value of measurements and their associated calculated values estimation through the prediction of a value, then estimating the uncertainty of the predicted value hence computing an average between the predicted value and the measured value. Then comes the extended Kalman filtering method where it is the nonlinear version of the Kalman filtering which it linearizes about the current mean and covariance. The main benefit is that the gain and covariance equation converges to a constant values resulting in a more accurate convergence of the estimation. This will be very effective in calculating the state of charge but at the same time, it is not easy to handle the calculation as it can be very tedious.

Besides that, a switching isolating device is still needed for the PWM Solar Charger. This would be much more convenient for the user of the electric vehicle instead of manually turning on and off the switch. And also this will help to increase the performance of the solar charger but if another component is added into the solar charger, much thought have to be considered about its voltage and current distribution in the circuit. Finding the right component for this switching isolation device could be a hassle too as any usual components couldn't be used in this circuit mainly due to the absence of the auxiliary battery.

In addition, a MPPT system can be integrated with the solar charger. MPPT is known as the maximum power point tracking which is an algorithm that have a controller that extracts the maximum power available from the solar panel from the sun. This highest voltage where the solar panel can produce maximum power is known as the maximum power point. The MPPT will compare the output of the solar panel and compares it to the battery voltage and adjust itself to fix the best power that a solar panel can produce to charge the battery at a optimum charging, converting it to the best voltage to get the maximum current into the battery. This will definitely complement with the PWM Solar Charger where it helps to obtain the optimum voltage input at all times.

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APPENDICES