FAST CHARGING SYSTEM FOR LEAD ACID BATTERIES OF ELECTRIC VEHICLE

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

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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 **"FAST CHARGING SYSTEM FOR LEAD ACID BATTERIES OF ELECTRIC VEHICLE"** was prepared by **TAN CHUAN WEI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Nowadays, fossil fuels are getting lesser and going to use up in future if continue consuming this high amount of fossil fuel. Other than that, environment is polluted because of greenhouse gas emission from the burning of fossil fuel. Therefore, renewable energy is introduced and emphasized in many fields to reduce the usage of fossil fuel. Electrical vehicle technology is one of the important ways to reduce the usage of fossil fuel and very important in future when fossil fuel is used up. So, in future when there are more electrical vehicles is used, many petrol stations will change to EV charging stations. Fast charging system definitely is very important for the EV charging stations to reduce the customer's time of waiting EV to charge and to improve EV economics. In this paper, fast charging system for lead acid battery will be proposed. In order to achieve that, behaviour of lead acid battery and charging method will be discussed. For example, types of lead acid battery, state of charge, state of health, constant voltage theory, constant voltage theory, pulse charging and more. Dual input charging method and pulse charging method are used for this project. Dual input charging method is faster than normal charging method while pulse charging method will increase battery service life without much slow down charging speed. Therefore, dual pulse charging method is proposed in this project.

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LIST OF SYMBOLS / ABBREVIATIONS

EV	electric vehicle
ICE	internal combustion engine
HEV	hybrid electric vehicle
DOD	depth of discharge
AGM	absorbent glass mat
SOC	state of charge
OCV	open circuit voltage
SOH	state of health
PWM	pulse width modulation

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, ICE vehicles are everywhere as the technology of ICE vehicle is very mature. As the result, fossil fuels were used a lots and getting lesser from time to time. Other than that, the environment was affected by the gases produced by the combustion of fossil fuels. To solve this problem, EV technology had been introduced since 1800. However, this technology still not mature yet. The immature of EV technology causes low demand of EV in the market. To remedy the immature of EV technology, hybrid electric vehicle (HEV) system was introduced. HEV can function with electrical power and having gasoline engine as the backup energy.

In order to achieve mature technology of EV which the vehicle fully function based on only electrical power supply from battery. Since the battery is the main components of EV, the battery charging speed is one of the important challenge of EV technology.

1.2 Aims and Objectives

The aim of this research project is to develop a fast and efficient charging system for EV batteries.

The objectives of this research project are:

I. To study the characteristics and behaviours of lead-acid batteries.
II. To study the effect of different charging method on lead acid batteries.
III. To develop a fast charging method for lead acid batteries in EV.
IV. To reduce charging period and save time.

CHAPTER 2

LITERATURE REVIEW

2.1 Lead Acid Battery

Lead acid battery is the oldest rechargeable battery and still in used as it can produce high surge current and low cost compared to newer technology. So lead acid battery is a good choice for motor vehicles. Lead acid battery consists of negative electrode lead plate, positive electrode lead dioxide plate and electrolyte of water and sulfuric acid. Figure 2.1 below shows the structure of lead acid battery. Equations 2.1, 2.2 and 2.3 shows the chemical reactions within the SLA batteries during charging and discharging cycles. Figure 2.2 shows the chemistry of lead acid batteries.

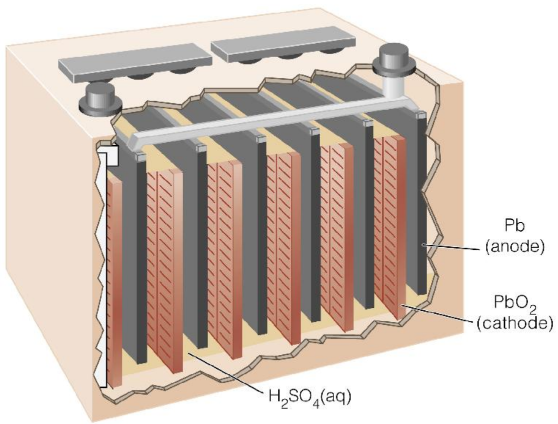

Figure 2.1: Structure of Lead Acid Battery

Reversible chemical reactions at the two electrodes allow the battery to be charged and discharged.

The reactions at anode are

$$Pb + SO_4^{2-} \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} PbSO_4 + 2_{e^-} \tag{2.1}$$

The reactions at cathode are

$$PbO_2 + 4H^+ + SO_4^{2-} + 2_{e^-} \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} PbSO_4 + H_2O \tag{2.2}$$

The total discharge reaction is

$$Pb + PbO_2 + 2HSO_4^- + 2H^+ \rightarrow 2PbSO_4 + 2H_2O + \text{energy} \tag{2.3}$$

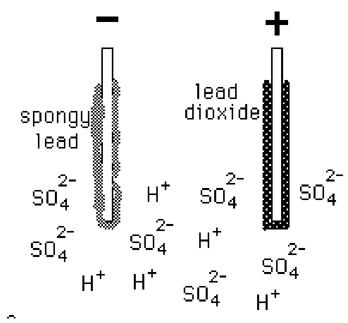

Figure 2.2: Chemistry of Lead Acid Batteries (HyperPhysics, 2015)

For typical lead acid battery, the voltage of single cell produced is approximately 2.1 volts. So, there are six cells for a 12.6V lead acid battery.

2.2 Types of Lead Acid Battery

There are two common types of lead-acid batteries which are the starter battery and the deep-cycle battery.

2.2.1 Starter Battery

Starter battery is normally used to start up vehicle engine by generate a short burst of large power. So, it can deliver high current but cannot be deep-cycled. The design of starter battery is multiple of thin lead plates arranged in parallel. The number of plate in starter battery is more than number of plate in deep cycle battery. The lead plates are thin and in appearance of sponge-like fine form. These two designs have increase the surface area of the plate so that maximum power density and low resistance can be achieved. Figure 2.3 shows the internal structure of starter battery.

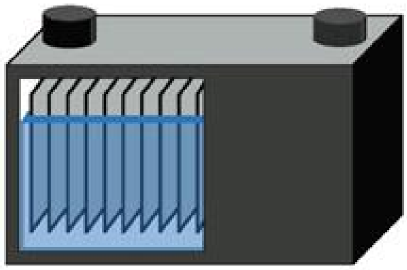

Figure 2.3: Internal Structure of Starter Battery (Battery University, 2016)

The discharge of starter battery is short and it recharges while the vehicle is driving. So, starter battery emphasize more on power rather than on capacity. The starter battery should not be used for deep-cycle purposes as its cycle performance is weaker than a deep cycle battery. Normally, the DOD of starter battery should not more than 30% because it may left only 130 to 150 cycles. The higher the DOD, the lesser the life cycle of the battery. Therefore, starter battery is not suitable for EV. Table 2.1 shows the comparison between starter battery and deep-cycle battery in terms of life cycle against battery DOD.

Table 2.1: Cycle Performance of Starter Battery and Deep-cycle Battery (Battery University, 2015)

Depth of Discharge	Starter Battery	Deep-cycle Battery
100%	12–15 cycles	150–200 cycles
50%	100–120 cycles	400–500 cycles
30%	130–150 cycles	1,000 and more cycles

2.2.2 Deep-cycle Battery

Deep-cycle battery has high cycle count and maximum battery capacity compared with starter battery. As seen as Table 2.1 above, deep-cycle battery can be deeply charged and still has much more life cycles compared with starter battery. The thick lead plate of the deep-cycle battery has increase the life cycles when it is deeply charged. Deep-cycle battery can produce longer duration of electrical energy as the DOD is much higher than starter battery with the same battery life cycles. Figure 2.4 shows the internal structure of deep-cycle battery.

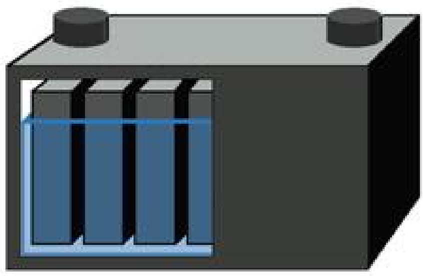

Figure 2.4: Internal Structure of Deep-cycle Battery (Battery University, 2015)

Absorbent Glass Mat battery (AGM) are high performance lead acid battery where the electrolyte is absorbed in a mat of fine glass fibers. This design make the battery spill-proof and is more resistant to shock and vibration. The AGM batteries are normally used in high-end vehicles to power car accessories (Battery World, 2016). Therefore, they are also suitable to be applied in the EV used in this research.

2.3 Battery Conditions

2.3.1 State of Charge (SOC)

SOC of a battery is one of the most important parameter of a battery. SOC describes the amount of energy left in the battery with reference to the total capacity of the battery. SOC can protect battery and improve battery life by prevent overdischarge or overcharge. Other than that, with the accurate estimation of SOC, the battery performance can be known so that the driving range of EV can be determined. The SOC value must be an absolute value based on the capacity of the battery when new, not a percentage of current capacity which cause errors due to battery ageing (Electropaedia, 2005). There are some methods to measure the SOC of lead acid battery will be discussed below.

2.3.1.1 Hydrometer or Specific Gravity Method

SOC of lead acid battery can be known by the specific gravity of the battery. Hydrometer is used to measure the specific gravity of the battery, but this method only can be applied for flooded batteries. This method is dangerous and dirty because it involves contact with the battery solution which contains sulphuric acid and lead sulphate (Blue Sea Systems, 2016). The sulphuric acid become heavier when lead acid is charging. In other way, when lead acid battery is discharge, the concentration of sulphuric acid in the electrolyte will be decrease. This cause the concentration of the electrolyte decrease, hence the specific gravity will reduce too. Specific gravity measurement is slow and inconvenient. (D.Jaya Deepti, 2006)

2.3.1.2 Voltage Method

Voltage method to determine the SOC of the battery is monitoring the voltmeter voltage readings. The difference between a fully charged battery and fully discharged battery is only 1.0V in a 12V battery (Blue Sea Systems, 2016). Voltage method is simple, but it is inaccurate due to difference in battery voltage profiles as each battery has its own unique discharge behaviour. Moreover, temperature can also affect the voltage of the battery, where higher temperature increases the voltage and lower temperature decreases the voltage (Battery World, 2016).

In order to get more accurate results, the battery needs to be open circuit state and stay for four hours. Furthermore, lead acid battery is recommended by manufacturers to be in open circuit state for 24 hours. This will cause active duty battery impractically to use open circuit voltage method. The relation of state of charge, specific gravity and open circuit voltage of lead acid battery is shown in Table 2.2.

Table 2.2: The Relation of SOC, Specific Gravity and OCV of Lead Acid Battery (Trojan Battery Company)

Percentage of Charge	Specific Gravity Corrected To	Open-Circuit Voltage					
		6v	8v	12v	24v	36v	48v
100	1.277	6.37	8.49	12.73	25.46	38.20	50.93
90	1.258	6.31	8.41	12.62	25.24	37.85	50.47
80	1.238	6.25	8.33	12.50	25.00	37.49	49.99
70	1.217	6.19	8.25	12.37	24.74	37.12	49.49
60	1.195	6.12	8.16	12.27	24.48	36.72	48.96
50	1.172	6.02	8.07	12.10	24.20	36.31	48.41
40	1.148	5.98	7.97	11.89	23.92	35.87	47.83
30	1.124	5.91	7.88	11.81	23.63	35.44	47.26
20	1.098	5.83	7.77	11.66	23.32	34.97	46.63
10	1.073	5.75	7.67	11.51	23.02	34.52	46.03

2.3.1.3 Amp-Hours Remaining Method

The best way to measure the SOC of a battery is to continuously monitor voltage, amperage, and ampere hours remaining. This method involves complex calculations of the energy available, energy consumed, and energy returned to the battery in charging. This method includes important element of time in the calculation (Blue Sea Systems, 2015).

2.3.2 State of Health (SOH)

State of health (SOH) is a measurement of the performance of a battery. It is obtained by comparing the current performance with specific performance of new battery. A new battery will have SOH of 100% and when it experiences SOH 0%, it reaches minimum acceptable performance which is end of life (EOL) (Suozzo,C.,2008).

$$\text{State of Health (SOH)} = \frac{\textit{Measured parameter}}{\textit{Rated parameter}} \times 100\% \qquad (2.4)$$

2.3.3 Battery Capacity

Battery capacity is the electric charge stored in a battery which measured in unit of ampere-hours (Ah). Ampere-hours means the battery can discharge an amount of current over a time (Battery World, 2016). The higher the capacity of the battery, the longer duration the battery can supply electrical energy.

$$\text{Capacity (Ah)} = \text{current (A)} \times \text{time (h)} \qquad (2.5)$$

2.4 Charging Method

In order to charge a battery, there is minimum voltage to do that. The minimum voltage to charge lead acid battery is 2.15V per cell which is 12.9V for a 12V lead acid battery. The charging voltage can be increased for faster charging. The typical charging voltage range for a 12V lead acid battery is between 12.9V and 14.1 V which can used to charge a fully charged lead acid battery safely. The higher voltage can be applied if the battery is not fully charged (Power Stream, 2016). By the way, there are many methods to charge lead acid battery. For example, constant voltage charging, constant current charging, two steps charging, pulse charging, burp charging and more.

2.4.1 Constant Voltage Charging

Constant voltage charging is basically DC power supply charging. AC power supply can be used by working together with step down transformer and rectifier to supply DC voltage to charge the battery (Electropaedia, 2005). Constant voltage is supplied to the battery for the whole charging process. Whereas, high initial current is provided to the battery and the charging current is decreased throughout the charging process. This is because there is high potential difference between charger and battery in the beginning. Throughout the charging process, the potential is reduced. Figure 2.5 shows the constant voltage charging characteristics.

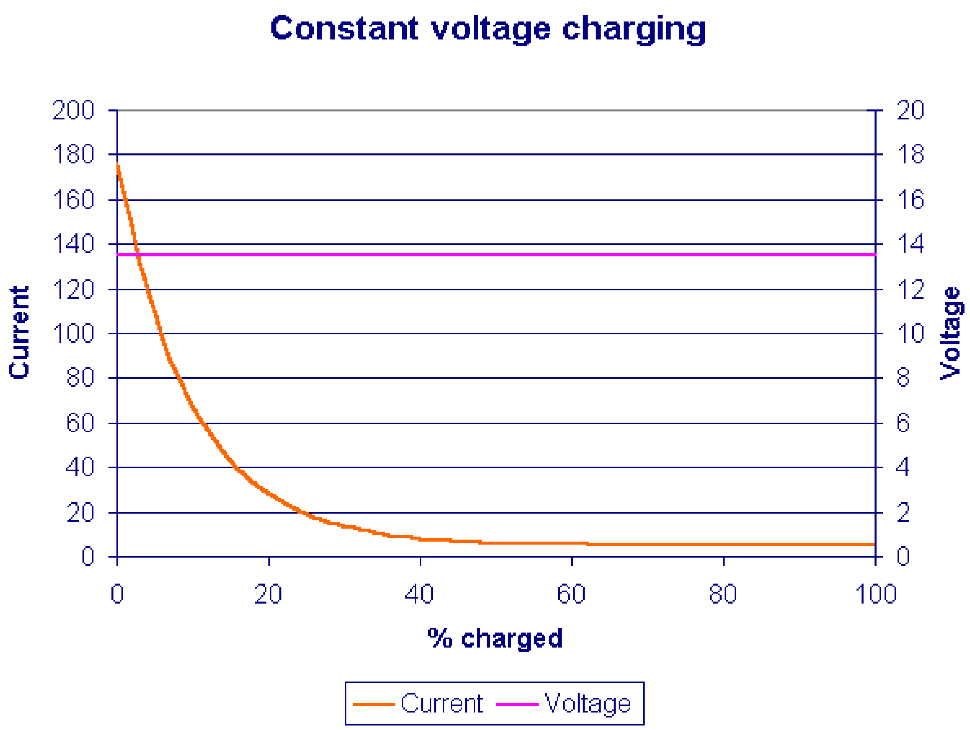

Figure 2.5: Constant Voltage Charging Characteristics (Hills,P.,2004)

2.4.2 Constant Current Charging

In constant current charging method, the current is controlled to provide uniform current flow and the voltage will be changing to maintain the constant current as shown in figure 2.6. Low constant current charging will charge slowly while high constant current charging will charge fast.

Low constant current charger normally is in simple design and cheap. The battery is provided with low constant current until the battery is fully charged. The user have terminate the charging himself to prevent the damaging of battery due to overcharging. For high constant current charging method, the battery is supplied with high current until fully charged. This charging method greatly reduces the charging time of the battery. For safety purpose, it needs a monitoring circuit to monitor the temperature of the battery and a controller to terminate the charge. However, it has negative long-term effect. Large constant current charging will form large metallic crystal in the battery that will increase the battery internal resistance which reduces the battery capacity and shorten its service life (Baroody,R.,2009).

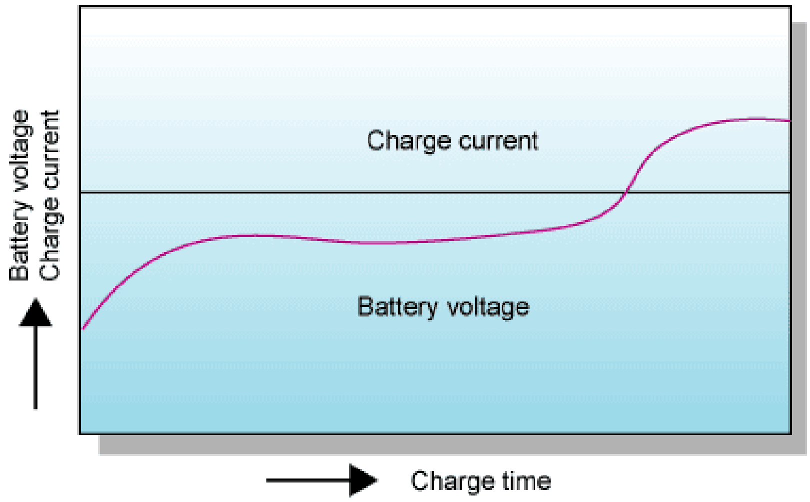

Figure 2.6: Constant Current Charging Characteristics (CSB Battery, 2005)

2.4.3 Constant-Voltage Constant-Current Charging

Constant voltage constant current charging method is an enhance method of high constant current charging. This method will provide initial constant current to the battery until predetermined voltage value is achieved, then constant voltage is provided to battery until charging current drops to very low. Constant-voltage constant current charging method will also cause same negative long-term effects like high constant current charging method but at a lesser degree. Figure 2.7 shows the characteristic of constant voltage constant current charging method.

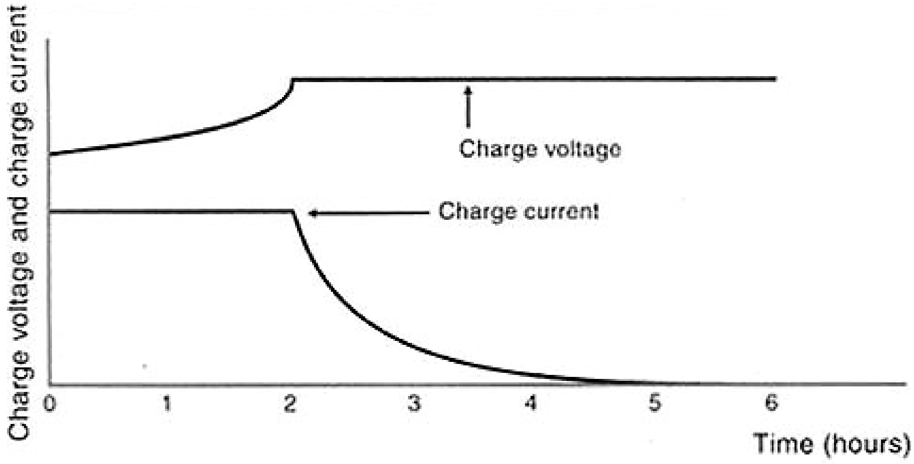

Figure 2.7: Constant-voltage Constant-current Charging Characteristics (BatteryWholesale, 2014)

2.4.4 Pulse Charging

Pulse charging is a method of charging the battery with charge current in pulses. There are charging period and rest period from the pulses. By varying the pulse width modulation, the charging rate can be adjusted precisely. The charging rate will be increased when the frequency of the input pulse charging current is increased. The chemical actions stabilise in the battery during the short rest period between the pulses. Unwanted chemical reaction such as crystal growth and gas formation at the electrode can be reduced. Figure 2.8 shows an example of current waveform in pulse charging.

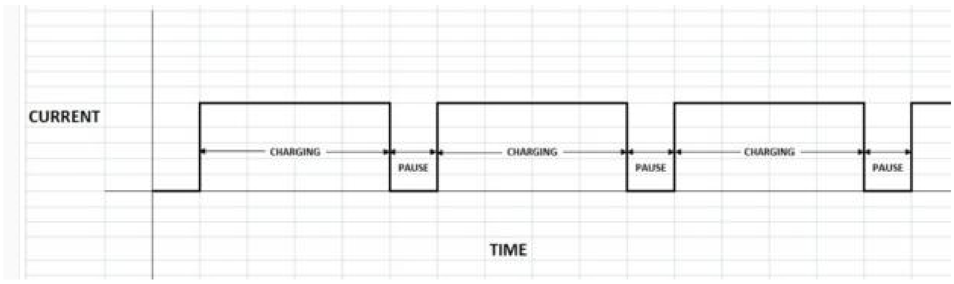

Figure 2.8: Waveform of Current in Pulse Charging

2.4.5 Negative Pulse Charging

Negative pulse charging is also known as burp charging. As shown in Figure 2.9, it provides a short negative discharge pulse during the rest period in between charging pulse. The discharge pulse is to depolarise the cell for five milliseconds with two to three times of the charging current. The overall charging process and the stabilisation process are speed up as the gas bubbles at the electrodes are dislodged by these pulses.

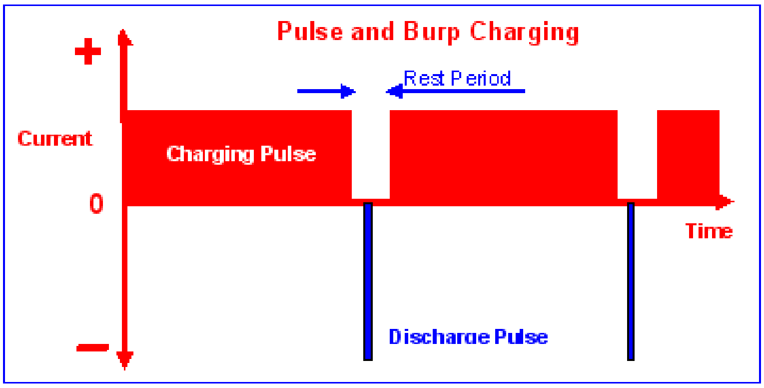

Figure 2.9: Pulse and Burp Charging Characteristics (Electropaedia, 2005)

CHAPTER 3

METHODOLOGY

3.1 System Design

The development of EV is getting higher and faster now due to power source and environmental issues. Normally, users will charge their EV overnight to perform for next day. However, when users travel for long distances, they need to charge their EV during the travelling. So, if they need to wait an overnight to charge the EV, the transportation is not effective and wasting time. This will cause the demand of EV become low. In order to solve this problem, fast charging system is proposed in this research paper.

From the discussion on charging method previously, pulse charging is selected for this proposed charging system. Besides that, a new charging method is proposed which is during the charging period, the batteries will change to parallel form for charging. After finish charging, the batteries change back to series form. Figure 3.1 shows the block diagram of proposed charging system.

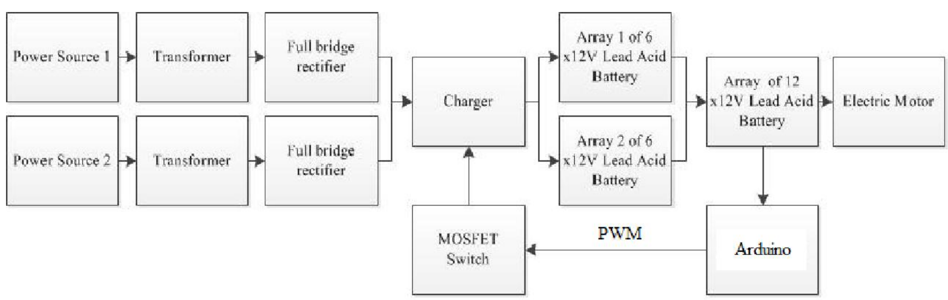

Figure 3.1: Block Diagram of Proposed Charging System

3.2 Circuit Design

In this proposed charging system, the circuit contain transformer, full bridge rectifier, charger, Arduino, MOSFET switch, lead acid battery and sensor.

3.2.1 Power Source

The power source is from the AC 240V 13A 3-pins socket. So the transformer is used to step down the voltage. The lead acid batteries will charge better in DC power rather than AC power. So, the full bridge rectifier is used to produce DC voltage.

A 240V primary 28V secondary transformer is used for the charger circuit. This transformer is used as it has higher maximum load current which is 5A with the rating of 140VA. Figure 3.2 shows the 240V primary 28V secondary 140VA shell type transformer. The accuracy of the rating of the transformer is depending on the manufacturer which mostly around plus minus 5% of the rated maximum load current. The transformer used is shell type and laminated so that the diameter of the transformer is shorter to reduce eddy current loss.

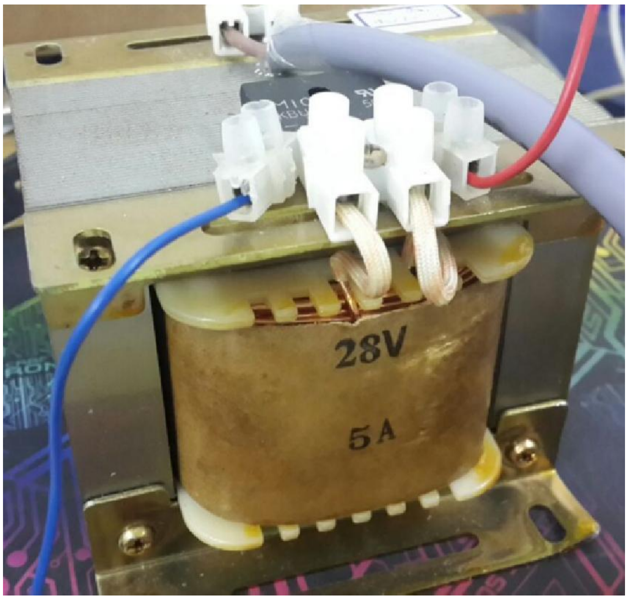

Figure 3.2: 240V Primary 28V Secondary 140VA Shell Type Transformer

After the power pass through the stepdown transformer, it still provide AC power. In order to supply DC voltage into charger circuit, it must pass through full bridge rectifier which constructed with four diodes. From figure 3.2, the full bridge rectifier inside a black casing is attached to the output of transformer.

3.2.2 Charger

In this project, a 30V 10A charger circuit is designed which can provide current adjustment and variable voltage. Voltage regulator chip LM723C is selected and implement in this charger circuit. LM723C is a voltage regulator that can provide adjustable output voltage from 2V to 37V. By LM723C itself, it can supply 150mA output current. With additional external transistors, it can provide output current up to 10A. Besides that, the maximum input voltage of LM723C is 40V which is in the safe zone as the power supply from transformer is 28V. Figure 3.3 show the charger circuit design constructed in Multisim.

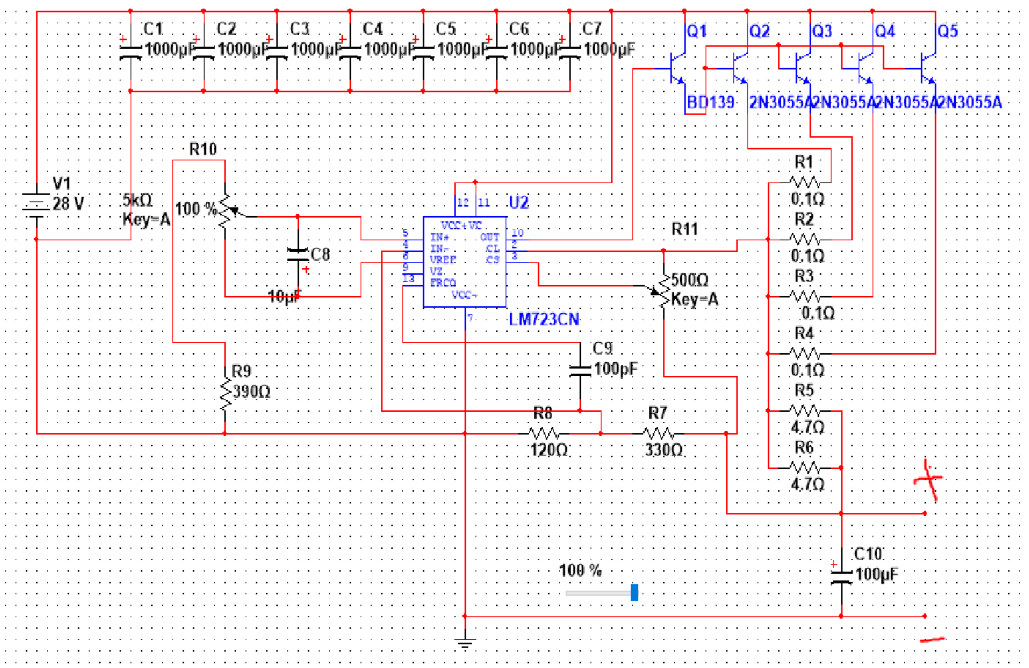

Figure 3.3: Charger Circuit Design

The capacitor bank is used to smooth out the rectified waveform from the full bridge rectifier to provide smooth DC waveform. The capacitor bank can changed to single large capacitor with suitable capacitance. The 2N3055 transistors are used to increase the maximum output current. The more the 2N3055 transistors connected together, the higher the output current. 2N3055 transistor is used because it is high current transistor with DC collector current of 15A. Moreover, it has collector emitter voltage of 60V and 200 °C maximum operating temperature so don't have worry it spoil as exceeding the limit. The heatsinks are attached to the transistors to dissipate the heat faster. 5W resistors are used to connect with 2N3055 transistors as the high power will pass through the resistors and will run rather hot with higher load. The BJT BD139 is used to activate all the 2N3055 transistors.

The 500ohm potentiometer can be varied to adjust the output current of the circuit whereas the 5kohm potentiometer need to adjust to get the desired output voltage. In the simulation a multimeter is connected to the output of the charger circuit to measure the output voltage and current range of the circuit. Figure 3.4 shows the multimeter connected to the circuit.

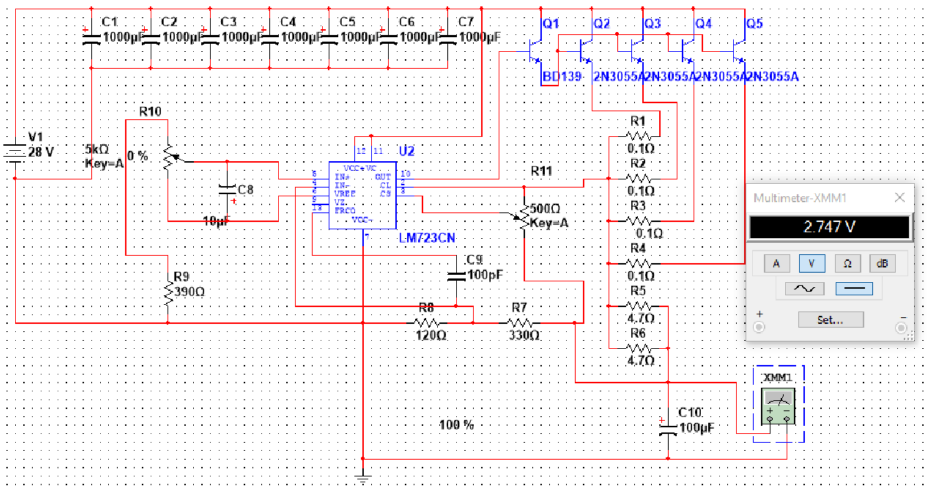

Figure 3.4: Multimeter Connected to Charger Circuit

Table 3.1 shows the range of output voltage and range of output current of charger circuit simulation.

Table 3.1: Range of Output Voltage and Output Current of Multisim Charger Circuit

Potentiometer (%)	Voltage(V)	Current(A)
0	2.747	300m
100	25.485	10.454

So, from the simulation the charger circuit can provide maximum output voltage of 25.485V and maximum output current of 10.454A. However the maximum charging current for AGM battery is 30% of the rated ampere hour rating which is 2.1A for 12V 7Ah battery used in this project. So the output current is adjusted to 2A, while the output voltage is adjusted to 14.2V as the maximum charging voltage for 12V AGM battery is 14.4V.

3.2.3 MOSFET Circuit

The MOSFET circuit in this project has two functions which are act as switch to open and close the charger circuit and to perform pulse charging. In this MOSFET circuit, IRFZ44N power MOSFET is used as it has characteristics of fast switching, ultra low on-resistance $R_{DS(on)}$ = 17.5mΩ and 175°C operating temperature. Besides that, it can withstand high voltage and high current with V_{DSS} = 55V and I_D = 49A. Figure 3.5 show the MOSFET circuit.

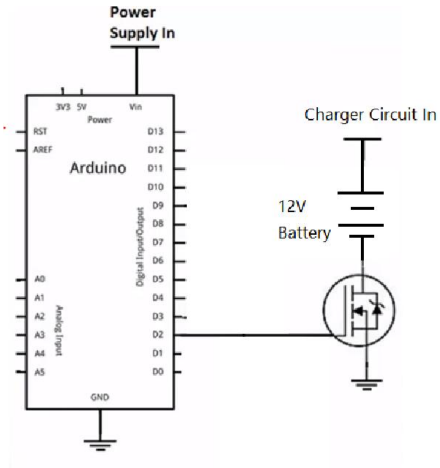

Figure 3.5: MOSFET Circuit

IRFZ44N power MOSFET is a logic level MOSFET with the low gate threshold voltage less than 5V, $V_{GS(th)}$ = 2V, so it can be easily control by signal from Arduino board.

3.2.4 Arduino Board, Sensor and Data Converter

ARDUINO MEGA 2560 is used to act as a charger controller for this research. Arduino board is easily programmable and easily to understand the command lines. It used to generate and adjust PWM to power MOSFET to perform pulse charging and acts switch to terminate the charging when the batteries are fully charged to prevent overcharging. Other than that, Arduino board also used to sense voltage, current and temperature.

Arduino board itself acts as voltmeter to measure the voltage across the battery terminals. Arduino board has maximum input voltage of 5V. If the higher voltage is applied to the pin of Arduino board, the pin will be spoiled and the Arduino board may be spoiled. The voltage of the battery has exceed the input voltage limit of Arduino board. So to sense the voltage across the battery, a voltage divider is constructed to limit the voltage enter Arduino board. The input terminals of voltage divider is connected to the terminals of battery and the output of voltage divider connected to the analog input pin of Arduino board. Then the Arduino software will show the results at laptop. The output terminals of charger circuit are also connected to the terminals of battery during charging process and the maximum output voltage of charger circuit from simulation is around 25V. For precaution, the voltage divider applied is divide the voltage by 5 times to get voltage lower than 5V Arduino board. Figure 3.6 shows the voltage divider circuit.

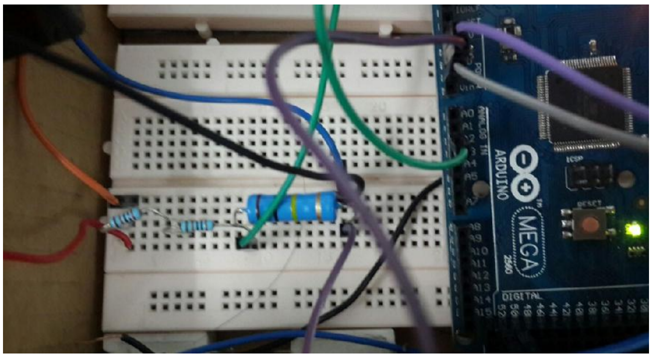

Figure 3.6: Voltage Divider Circuit

A hall effect current sensor ACS712 is used for the measurement of charging current flowing into the battery. Hall effect current sensor is a sensor that using electromagnetism to sense current and get voltage value to send out to the data line. As the output value is in voltage form so the output value is sent to Arduino board for converting by connect the data line to the analog input pin. In the Arduino board, the voltage value is converted into current value by using equation. The offset value is removed from the voltage value to get the actual value which is more accurate. The current sensor is powered by 5V from the Arduino board and grounded to Arduino board. Figure 3.7 shows the connection of current sensor ACS712 to Arduino board.

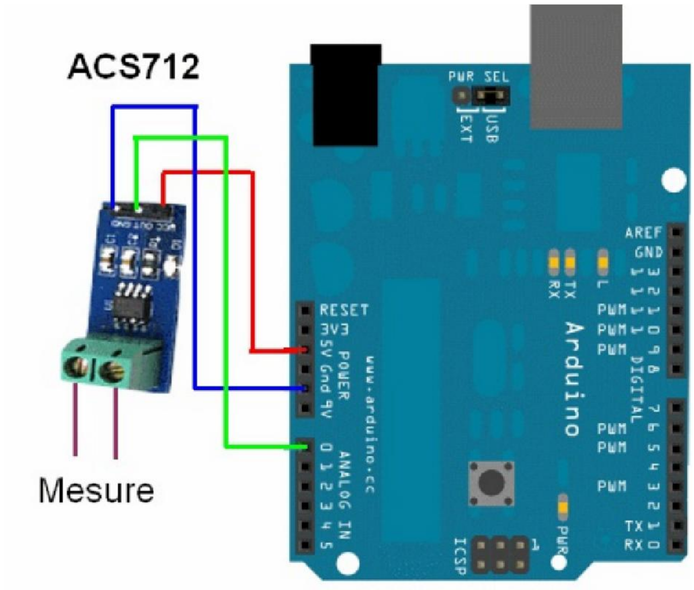

Figure 3.7: Connection of Current Sensor ACS712 to Arduino Board

For battery temperature measurement, temperature sensor DS18B20 is used in this project. DS18B20 is one wire temperature sensor and it is simple to use. The temperature sensor just placed and sticked at the surface of battery to measure the temperature of battery. Figure 3.8 shows the connection of temperature sensor to Arduino board.

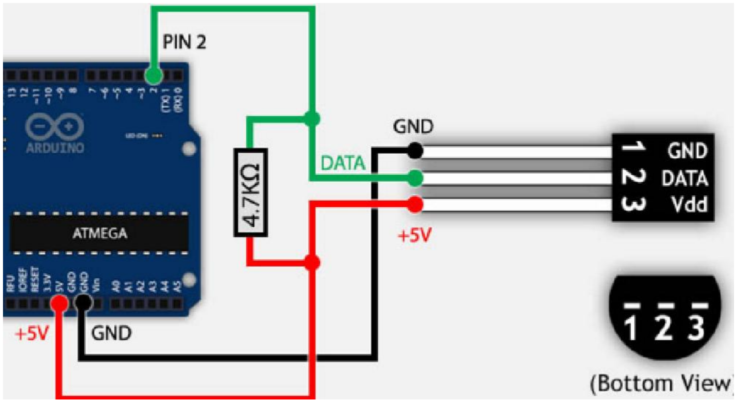

Figure 3.8: Connection of Temperature Sensor to Arduino Board

For data logging, microSD module is used to record the data shown in the Serial Monitor of Arduino software into a microSD card. The data will stored in microSD card inside a text file. The text file can be get by using card reader to access to microSD. Then the data can be imported to Microsoft Excel from the text file. Figure 3.9 shows the microSD module with microSD card and connection to Arduino board.

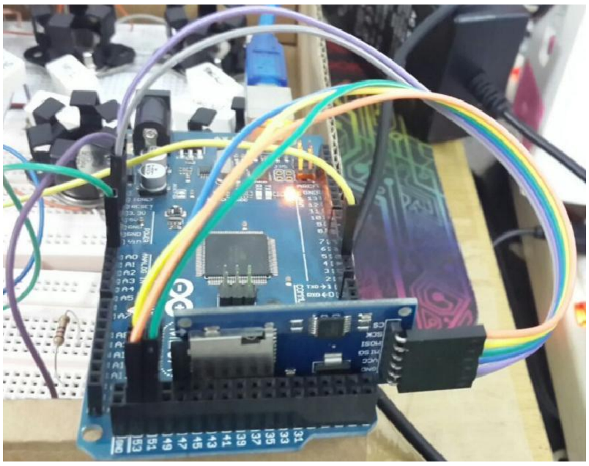

Figure 3.9: Connection of microSD module to Arduino Board

3.2.5 Battery Consideration

For the battery consideration in this project, deep cycle AGM lead acid battery should be used as it is used at the UTAR EV project. In order to do research on battery of EV, sealed lead acid battery is used as it has same battery characteristics so that the findings are more convincing. Sealed lead acid battery has advantages like low cost, low internal resistance, can be used for deep cycle usage and it is mature technology. Besides that, sealed lead acid battery has advantage of minimizing gassing effect and avoiding water loss. However, it has some disadvantages which are no suitable for high current discharge usage and it is heavy and bulky. To get more accurate open circuit voltage, sealed lead acid battery need resting period for recovery.

The battery used in UTAR EV project to power up the electric motor has rating of 144V and 175Ah. This high rating power is constructed by 12 pieces of 12V 175Ah AGM lead acid batteries connected in series. As this high capacity battery is very expensive, the sealed lead acid battery used for this research only has rating of 12V with 7Ah capacity which are much cheaper.

The suitable charging current range of sealed lead acid battery is between 0.1C rate and 0.3C rate which is the 10% to 30% of the battery capacity. So for 7Ah battery used in this research, the suitable range of charging current is between 0.7A and 2.1A. However, the maximum charging current of the battery maybe different based on different manufacturer.

3.3 Charging Algorithm

In this research paper, dual input pulse charging method is proposed as the fast charging system. As discussed in previous chapter, pulse charging method is selected because it can prolong the battery life and increase the charging efficiency. Pulse charging has charging period and resting period. The duty cycle percentage of pulse width modulation will determine the charging period and resting period. Figure 3.10 shows the different percentage of duty cycle of pulse width modulation. Then this pulse charging method is used to apply to the dual input charging system.

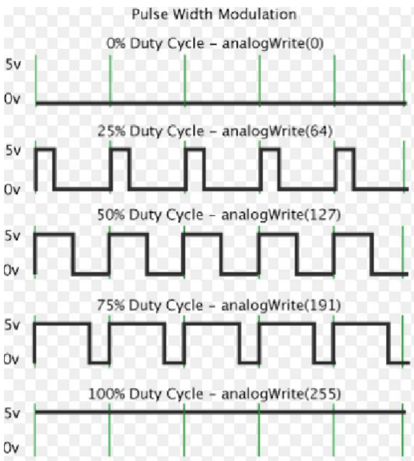

Figure 3.10: Pulse Width Modulation with Different Duty Cycle Percentage

In the proposed dual input charging system, the 12 pieces 12V batteries connected in series to power electric motor are separated into two arrays of series connection batteries with six pieces 12V batteries in each array. Then two charging inputs will applied to them, each array has own charging input. Each charging input come from the 240V AC source pass through step down transformer, rectifier and charger circuit. In the charging process, each array of batteries is isolated and charged individually. Therefore, the total capacity of each battery array is divided by half. With the same charging current to charge half number of batteries, the charging time is estimated can be reduced by half. Same amount of power supply must be applied to both arrays so that the charging time will be almost the same. After both battery arrays are fully charged, they are connected back together to supply the actual power needed by EV.

In this research, two 12V sealed lead acid batteries connect in series to represent 12 pieces 12V AGM batteries in EV project and each 12V sealed lead acid battery represent each array of six 12V AGM batteries in series. The charging profile of two 12V sealed lead acid batteries connected in series is compared with charging profile of one 12V sealed lead acid battery by using the same charging current to prove the dual input charging system has faster charging speed.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Charger Construction

Before start constructing the charger circuit, the functionality and capability of the circuit is tested by simulation using Multisim. The charger circuit then is built on breadboard after the simulation circuit is checked. The charger circuit is built on breadboard so that modification can be done easily. Figure 4.1 shows the charger circuit built on breadboard.

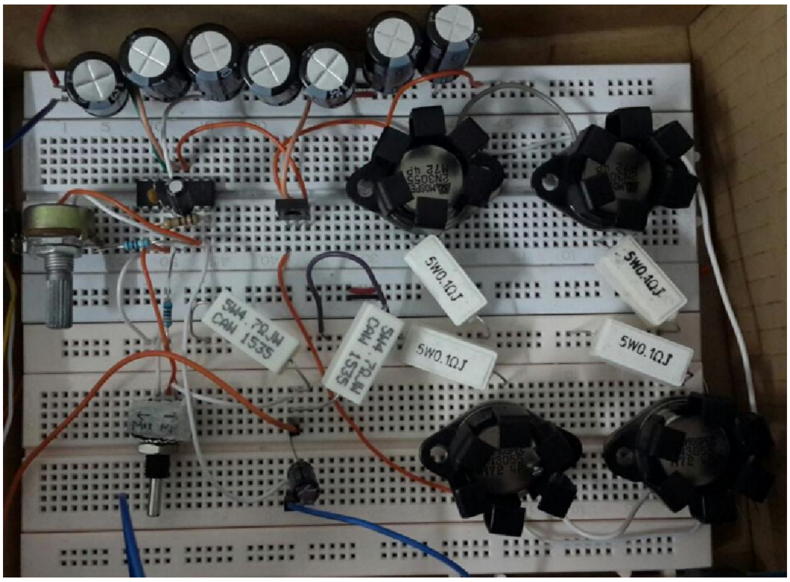

Figure 4.1: Charger Circuit Built On Breadboard

Since the dc source is needed to charge the battery, the ac voltage passed through full wave bridge rectifier after step down by the transformer. After ac voltage is passed through the full wave bridge rectifier, the negative waveform is rectified to positive waveform. Figure 4.2 shows the voltage waveform after rectification.

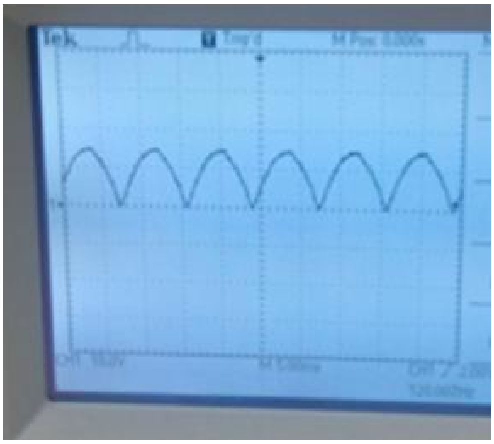

Figure 4.2: Waveform of Voltage Signal after Rectification

The maximum output voltage and maximum output current of charger circuit are measured to check avaibilty to use for both 24V and 12V charging. Figure 4.3 shows the maximum output voltage of charger circuit and Figure 4.4 shows the maximum output current of the charger circuit. Before start charging the sealed lead acid battery, the output voltage and output current is adjusted to the rated value by adjusting the potentiometers.

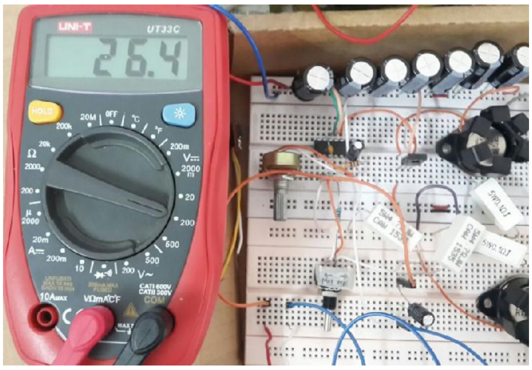

Figure 4.3: Maximum Output Voltage of Charge Circuit

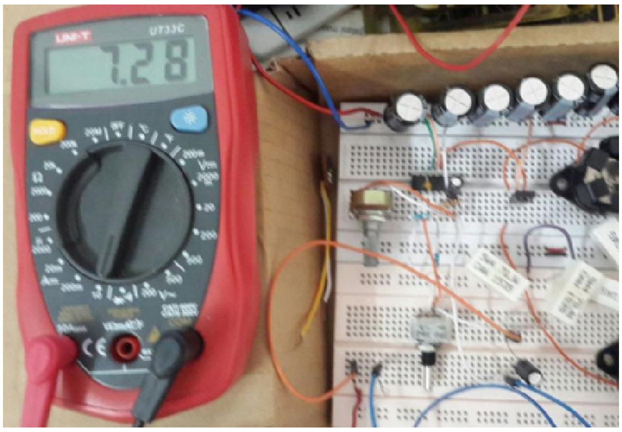

Figure 4.4: Maximum Output Current of the Charger Circuit

4.2 Charging Profile

In the charger circuit, 500ohm potentiometer is adjusted to vary the charging current and 5kohm potentiometer is adjusted to vary the charging voltage to act as different rating of battery charger. 24V charger with 2A charging current is adjusted to charge 24V battery that form by two 12V sealed lead acid batteries in series. Table 4.1 shows the initial open circuit voltage and final open circuit voltage of 24V battery. Figure 4.5 shows the charging profile of 24V battery.

Table 4.1: SOC of 24V Battery Before and After Charging with 2A Current

	Initial Voc(V)	Final Voc(V)
24V Battery	20.25	24.79

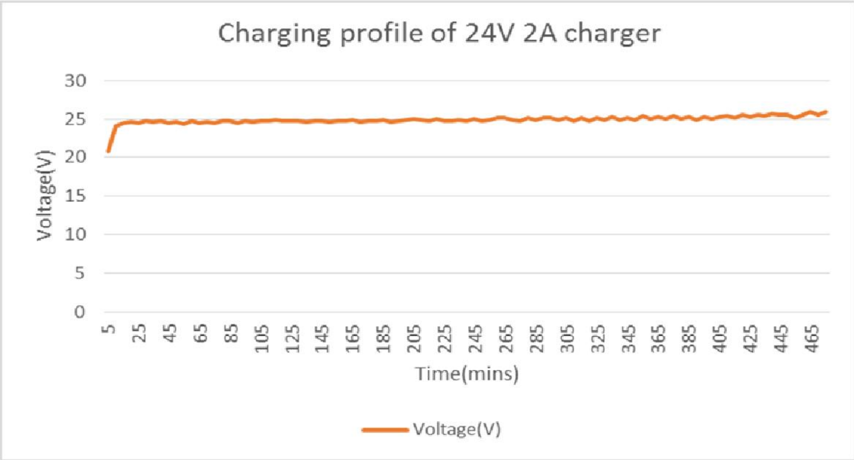

Figure 4.5: Charging Profile of 24V 2A Charger

The charger then adjusted to 12V and remain 2A to charge a single 12V sealed lead acid battery. Table 4.2 shows the initial open circuit voltage and final open circuit voltage of 12V battery. Figure 4.6 shows the charging profile of 12V battery with 2A charging current.

Table 4.2: SOC of 12V Battery Before and After Charging with 2A Current

	Initial Voc(V)	Final Voc(V)
12V Battery	9.97	13.14

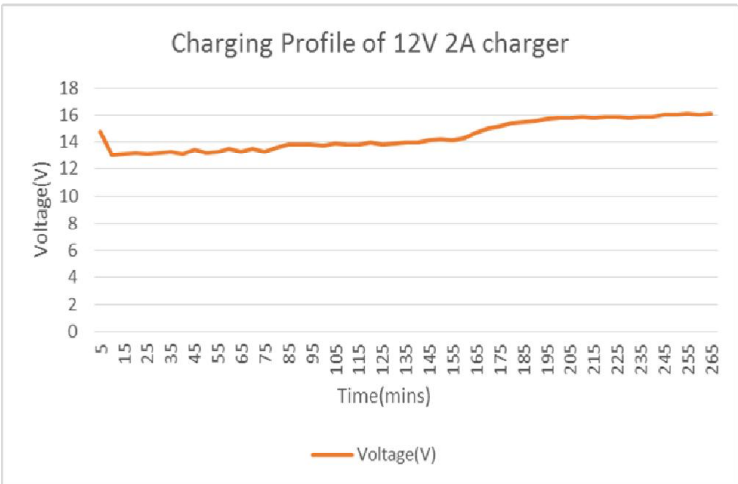

Figure 4.6: Charging Profile of 12V 2A Charger

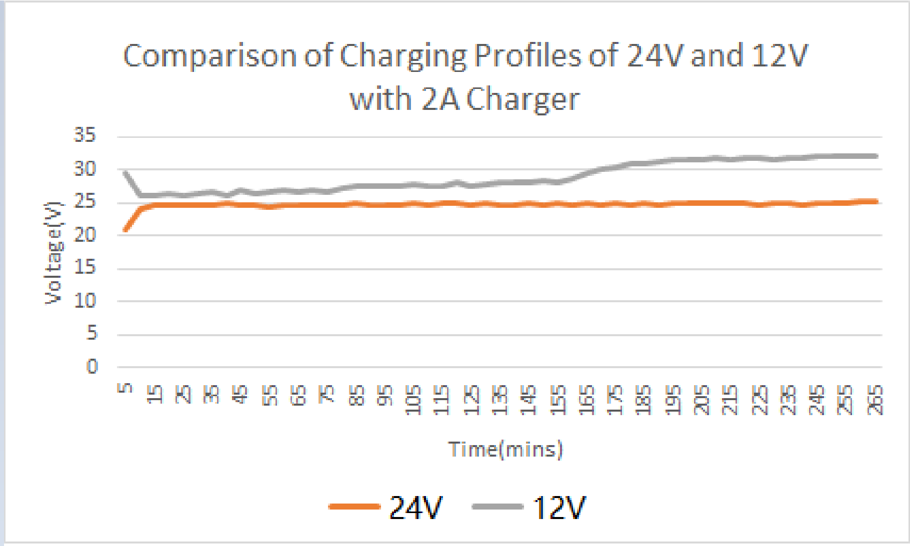

Figure 4.7: Comparison of Charging Profiles of 24V and 12V with 2A Charger

As dual input charging method is proposed, the results of 24V charger is compare with 12V charger with same charging current of 2A. The voltage readings of 12V is multiply by 2 as two 12V is in series after dual charging to compare with 24V charger. Figure 4.7 shows the comparison of charging profiles of 24V and 12V with 2A Charger. The results show that dual input charging is much faster than normal charging.

After that, pulse charging is applied to the charger circuit. In this pulse charging, 90% duty cycle of pulse width modulation is send to the charger circuit. Table 4.3 shows the initial open circuit voltage and final open circuit voltage of 12V battery for pulse charging. Figure 4.8 shows the charging profile of 12V battery with 2A pulse charging current.

Table 4.3: SOC of 12V Battery Before and After Pulse Charging with 2A Current

	Initial Voc(V)	Final Voc(V)
12V Battery	9.77	13.21

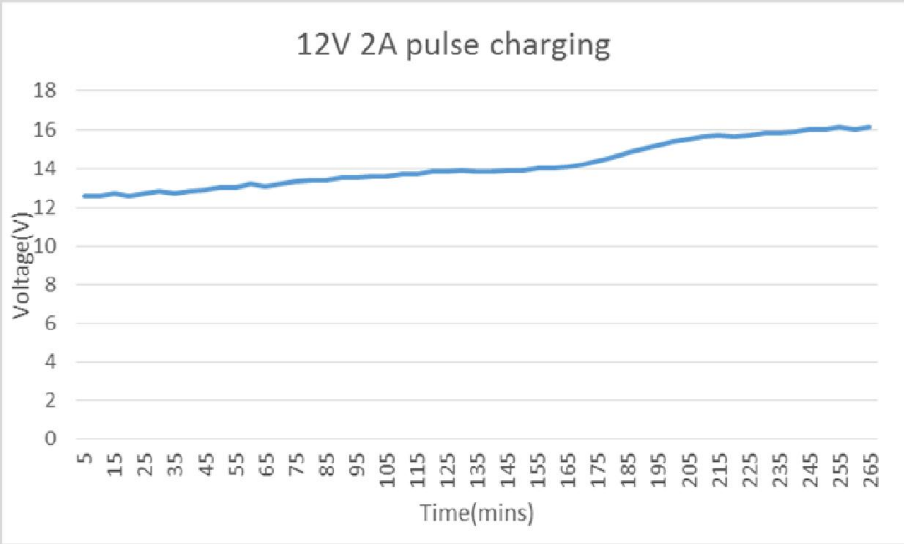

Figure 4.8: Charging Profile of 12V 2A Pulse Charging

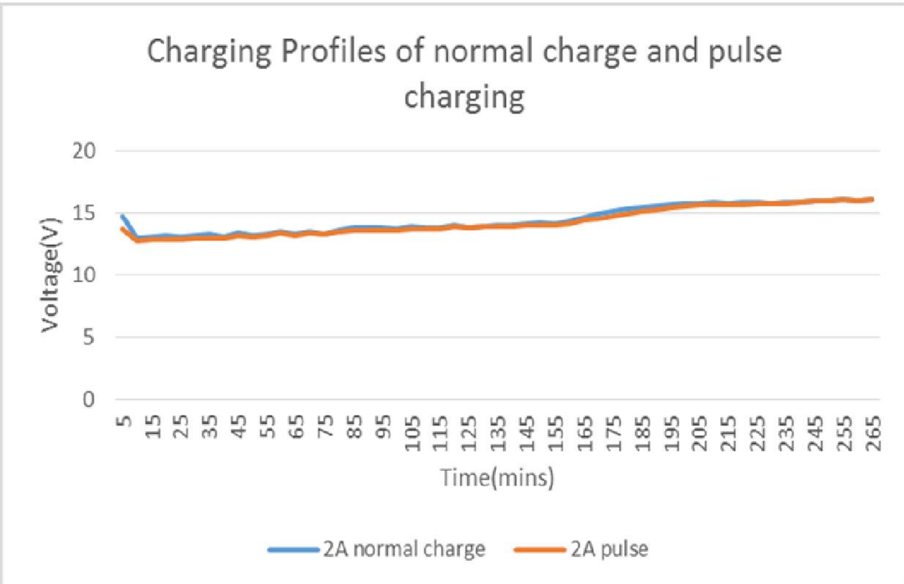

Figure 4.9: Charging Profile of 12V 2A Normal Charge and Pulse Charging

Figure 4.9 shows the comparison of charging profiles of 12V with 2A Normal Charge and Pulse Charge. From the result, pulse charging is slightly slower than normal charging with same charging current.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In order to charge a battery faster, higher current can be applied. However, with higher current, temperature of battery getting higher and will have overheating problem which cause the battery service life shorter.

Based on the experiment results, dual input charging method is proven that much faster than charging series of batteries by using more charger to separate charge the batteries. By using the same output current charger, more current can flow into the separately charged batteries as the total battery internal resistance is reduced. Therefore, the dual input charging duration will be shorter.

Besides that, pulse charging will be slightly slower than normal charging by using the same charging current. This is because the battery is stopped charging during the short resting period of the pulse width modulation. So, if lower percentage of duty cycle of pulse width modulation is applied, the charging speed will be slower. However, the pulse charging can reduce the heat produced by battery and prolong the battery service life.

5.2 Problems Encountered

The problem encountered in this research is the measurement of battery's SOC. Open circuit voltage measurement method is the most easiest way to measure SOC of battery but not so accurate. The sealed lead acid battery need a rest period to stabilise the open circuit voltage after charging or discharging so that the reading taken is more accurate. Besides that, the voltage reading recorded for data analysing is not the open circuit voltage since the battery need to continue the charging process when the voltage readings are recorded.

5.3 Recommendations

In order to solve the inaccurate SOC measurement problem, coulomb counting method is recommended. Coulomb counting method use the C-rate to determine charging rate and discharging rate.

For charging method, pulse charging with higher charging current method is recommended since the pulse charging has reduce the overheating problem. Besides that, programmable variable pulse charging by controlling duty cycle is suggested so that battery can reach optimum charging speed based on temperature or state of battery.

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APPENDICES

APPENDIX A: Arduino Coding for data logging

```
/*
  SD card datalogger
The circuit:
 * analog sensors on analog ins 0, 1, and 2
 * SD card attached to SPI bus as follows:
 ** MOSI - pin 11
 ** MISO - pin 12
 ** CLK - pin 13
 ** CS - pin 4

 */

#include <SPI.h>
#include <SD.h>

const int chipSelect = 4;

void setup() {
  // Open serial communications and wait for port to open:
```

```
  Serial.begin(9600);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB port only
  }


  Serial.print("Initializing SD card...");

  // see if the card is present and can be initialized:
  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    // don't do anything more:
    return;
  }
  Serial.println("card initialized.");
}

void loop() {
  // make a string for assembling the data to log:
  String dataString = "";

  // read three sensors and append to the string:
  for (int analogPin = 0; analogPin < 3; analogPin++) {
    int sensor = analogRead(analogPin);
    dataString += String(sensor);
    if (analogPin < 2) {
      dataString += ",";
    }
  }

  // open the file. note that only one file can be open at a time,
  // so you have to close this one before opening another.
  File dataFile = SD.open("datalog.txt", FILE_WRITE);
```

```
  // if the file is available, write to it:
  if (dataFile) {
    dataFile.println(dataString);
    dataFile.close();
    // print to the serial port too:
    Serial.println(dataString);
  }
  // if the file isn't open, pop up an error:
  else {
    Serial.println("error opening datalog.txt");
  }
}
```