BATTERY MANAGEMENT SYSTEM FOR ELECTRIC VEHICLE PASSIVE CELL BALANCING ON LITHIUM ION POLYMER BATTERY

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

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(Dr. Zainal Arif B. Burhanudin)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Azmeer Bin Abdul Majid

ABSTRACT

Automotive industry is moving forward for green technology which is Electric Vehicles. Battery is one of the critical components in an Electric Vehicle. Lithium Ion Polymer battery offers better performance compare to other types of the battery in the market. However, Lithium Ion Polymer battery is very sensitive to over voltage and under voltage which can be hazardous to the user. Moreover, the imbalanced cell in a battery affects the performance and life usage of the battery. By having a proper monitoring and balanced cell, it can prolong and maintain the performance of the battery. The purpose of this work is to adopt a passive cell balancing during the charging of Lithium Ion Polymer battery. This work produces State of Charge profile of Lithium Ion Polymer battery using measured parameters such as voltage, charging current and temperature. The work on battery testing was done to calculate the State of Charge and verified using Orion Battery Management System data. In this report, findings on both methods are discussed. A prototype of passive cell balancing was designed using a PIC16F877A microcontroller. However, the prototype is still under way. Therefore, the effectiveness cannot be determined at the moment.

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LIST OF ABBREVIATIONS

LiPo	Lithium Ion Polymer
SOC	State of Charge
BMS	Battery Management System

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Consumers are aware on this green technology to save the environment. Thus, automotive industry has develops a renewable energy which is Electric Vehicle to minimize petrol usage. Automotive manufacturers are moving forward in enhancing this technology as a reliable product in the market. Battery consumption on Electric Vehicles (EV) model leads to energy saving. At the moment NiMH battery type is the mainstream technology for Electric Vehicle. However, Lithium Ion Polymer battery is being introduced on the market because it produces equivalent energy as the NiMH for longer period and half of the weight. Lithium Ion Polymer battery characteristic needs to be monitor because of it is sensitive to overvoltage and under voltage where it can shorten the life cycle. The imbalanced of the cells while charging need to be monitored to observe the cells. State of Charge is an expression in percentage to indicate the charging capacity of the cells [1]. Different type of battery has different characteristic which need to be consider to calculate SOC.

1.2 Problem Statement

Battery is one of the critical components in any electric or hybrid vehicle. Average battery life of a Lithium Ion Polymer battery is approximately about 6 years which is consider not reasonable due to high cost of the battery which approximately about $10,000-15,000. This type of battery is sensitive to over voltage and under voltage. The imbalanced state of charge in cells due to repeated usage and manufacture defects affect the performance of the battery.

1.3 Significant of Project

Cell balancing approach gives better enhancement in battery technology. The repeated usage of the imbalanced cells decreases the performance before the average time. The balance charging of the cells give better performance and life usage. Therefore, implementing a cell balancing is important for battery technology.

1.4 Objectives

1. To measure State of Charge for Lithium Ion Polymer battery
2. To validate State of Charge measurement using Orion BMS
3. To build a prototype of passive cell balancing using microcontroller
4. To investigate the effectiveness of passive cell balancing

1.5 Scope of Study

The author will focus on these following procedures:

1. Understand concept of Battery Management System using Orion BMS
2. Determine State of Charge for Lithium ion Polymer battery and validate using Orion BMS
3. Design and build a prototype of passive cell balancing on monitoring 2 cells of the LG Chem Lithium Ion Polymer battery

CHAPTER 2
LITERATURE REVIEW

In automotive industry has open new renewable energy concept which is Electric Vehicle to reduce fuel consumption and carbon dioxide emission as global are concern on green environment. This powered by motor concept can produce power on acceleration and also generate energy from braking system which will be stored in large battery packs [2].

2.1 LG Chem Lithium Ion Polymer Battery

Battery packs system does contribute on to green technology. According to California Cars Initiative, eight hours charged of a large pack battery can drive up to 100 miles. The essence of battery is improving in miles per dollar and reduced kilograms of carbon-dioxide per mile conclude by K. Michael. There are many types of battery in the market for electric vehicle usage. However, research being done that lithium ion polymer battery has better efficiency in terms of higher power, energy density and higher single cell voltage [4][7]. According to K. Michael in his paper, replacing a lithium ion battery improve 150% energy storage.

For this project, lithium ion polymer battery was chosen for the testing. The less weight and higher life cycles are among the factors this battery type is selected. The state of charge capacity of this battery is determined and discuss in this report and normal operating voltage at 7.5v per module. This lithium ion polymer module able to operates at -20 to 50 Celsius which is suitable for testing [10]. The sensitivity of lithium ion battery need to be considered as it may cause hazardous and short time usage due to overcharge and undercharge state of the cells [7]. The battery specifications are attached in the Appendix A.

Figure 1: Lithium Ion Polymer Battery

2.2 Battery Management System (Orion BMS)

Characteristic of each cells differs in a long string series of battery is among the factor to an imbalanced voltage in cells [5][6][7]. To prevent this situation, Battery Management System being introduced to ensure each cell operating in optimizes condition whereby few variables can be measured thermal, state of charge, individual cell voltage and total pack voltage [7]. The main purpose of this system is to monitor the condition of each cell and maintains it operating limits to improve performance. This is suitable for harsh application as in automotive. This equipment is design for lithium ion family battery only and work as a passive cell balancer type [11]. The crucial moment on balancing the cells is when the battery is in charging and discharging condition. To achieve equal cells on the operation mode, the cell balancer needs to identify the individual cell capacity to ensure all cells in uniform condition [5]. This can be calculated with State of Charge (SOC) to ensure the cells are in limit condition or not overstressed. Battery profile of the module can be determined via the Orion utility software using CAN bus.

Figure 2: Orion BMS

2.3 Cell balancing

Cell balancing was invented to balance the imbalance cells in a particular battery. A bad cell will affect the performance of the whole battery and thus shorten the life usage of the battery. As LiPo battery cost is very high, by implementing the cell balancing user may extend the battery life that make the battery cost reliable. Below is researched done by M. Carlos comparing the balanced and unbalanced cell in terms of state of charge.

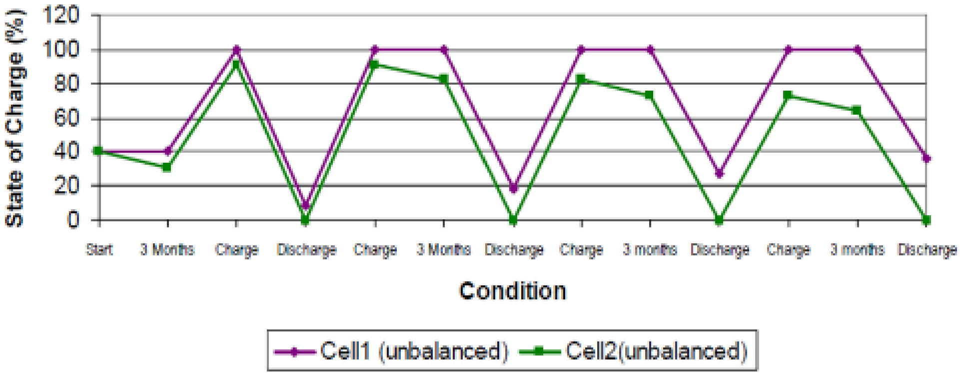

Figure 3: Cell Capacity with no cell balancing

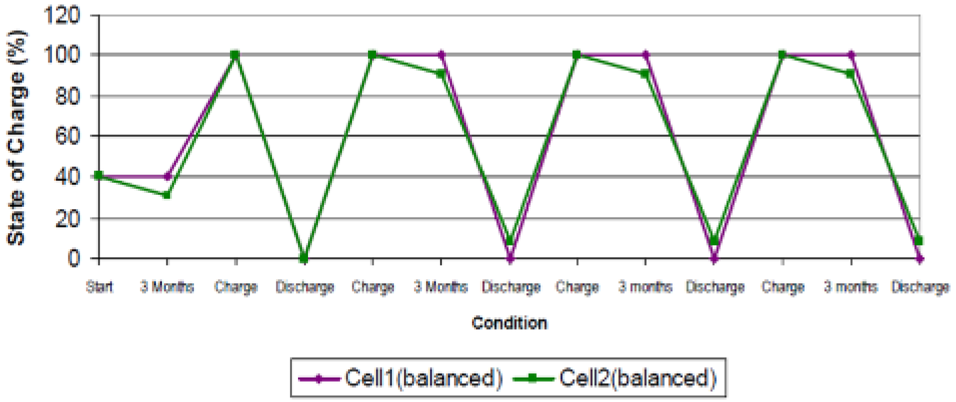

Figure 4: Cell Capacity with Cell Balancing

There are two types of cell balancing which are passive cell balancer and active cell balancer. Both of the methods have different pros and cons depend on the application. The old and simplest concept is the passive cell balancer where it only operates during charging cycle [6]. This concept applies bleed resistor to remove the extra voltage from the cell till it drop as the lower reference cell [5].

The wasted heat in this method results a lower efficiency in the application of electric vehicle [6]. However, active cell balancer approach transfer energy between the cells which is more efficient but complex than passive cell balancer [5]. William added in his thesis that active cell balancer can operate while battery discharging condition which will improve the long life of the battery. There are many types of topologies of cell balancing as below.

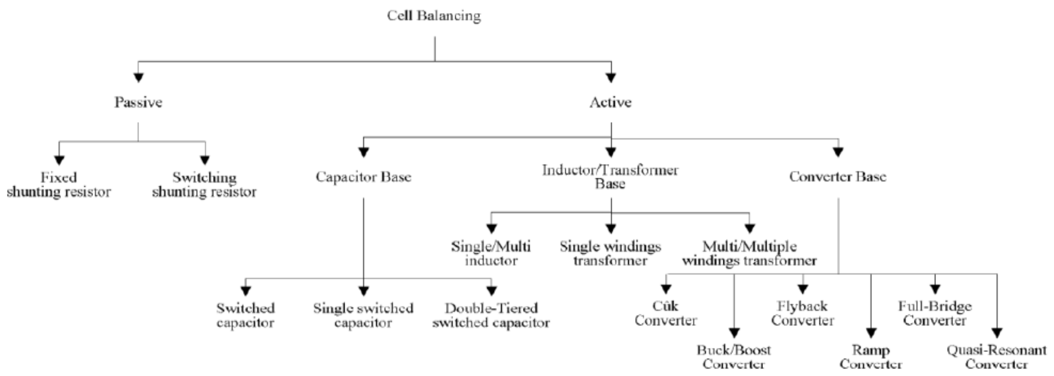

Figure 5: Passive and Active Topologies

In terms of cost reliability and complexity of the circuit, passive gives a better advantage than active. This project focuses on the switching shunting resistor method of passive cell balancing. It is based on removing energy from higher cell detected by microcontroller and switched the cell balancer as desired. This method is an improve method from the normal fixed shunt resistor where this concept reduces continuous energy dissipation.

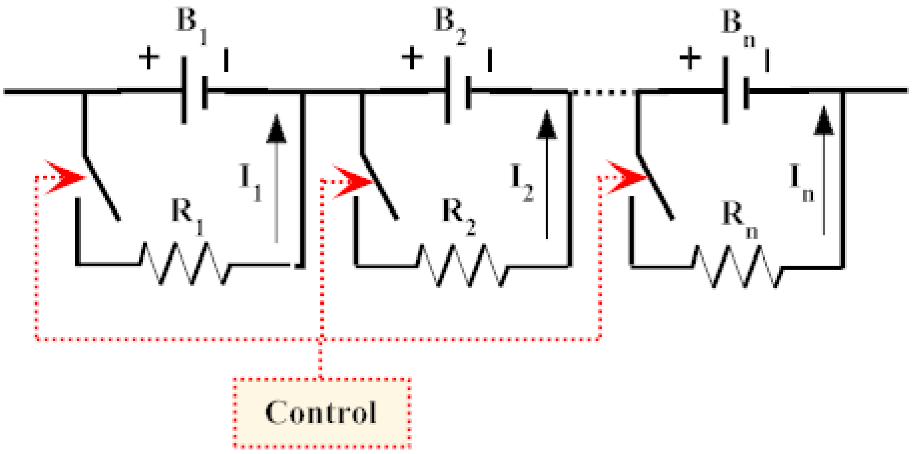

Figure 6: Controlled Shunt Resistor

2.4 Charging Method

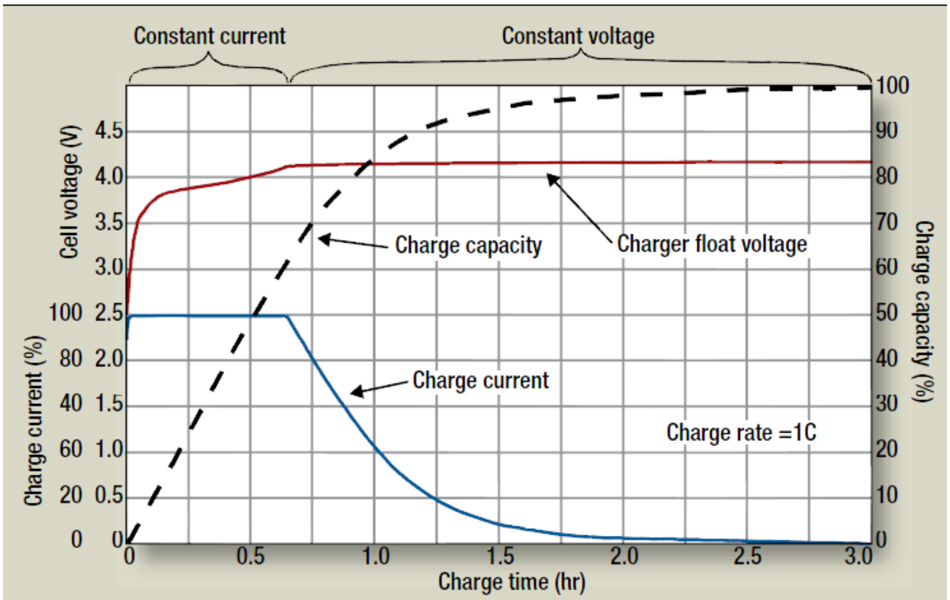

Figure 7: Charging Curve Method

Figure 7 shows an example of charging curve to a LiPo battery, a good charging is very important to ensure safety and to avoid damaging the battery [8]. Therefore, over charging a battery might affect the performance. There are several steps on charging a LiPo battery is as follows:

- Constant Current- This process implemented during the start of charging before it reach the nominal voltage value
- Constant Voltage- A constant voltage value implemented during the nominal stage and near to full charge.
- Trickle Charge- This method is to compensate the battery onto self-discharge when the battery is full to ensure full capacity being charged.

2.5 State Of Charge (SOC) Calculation Methods

State of Charge is the value to measure the capacity of the battery where it is an important element while charging and discharging the battery. The voltage, current and temperature influence the characteristic of the State of Charge (SOC). As Lithium Polymer requires high monitoring and proper charging, calculating the SOC is an important issue to avoid under charge or over charge for each cell. There were few methods on calculating the SOC. For this project author retrieved the SOC of the LiPo from the Orion BMS which use Open Circuit Voltage based (OCV) and Coulomb Counting.

2.5.1 Open Circuit Voltage Estimation

This method calculates the SOC from the voltage transition while charging and discharging. Other parameters might affect the accuracy of this SOC such as temperature. However for this project, the temperature does not influence as author only focus on 1 unit module of battery at room temperature.

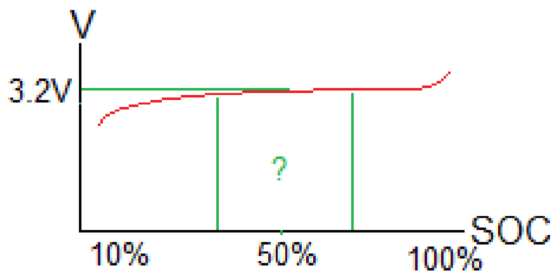

Figure 8: Open Circuit Voltage Estimation

2.5.2 Coulomb Counting Calculation

Coulomb Counting method is based on current charging calculation to measure the State of Charge (SOC). The current sensor must be accurate to have better value of SOC. The first point of the remaining capacity must be known before applying this formula. This is the formula for Coulomb Counting.

*SOC= Remaining SOC+ [Current_Charge (Ampere) * Time (Hours) / Battery Capacity (Ah) x 100]*

2.6 Microcontroller (PIC 16F877A)

Microcontroller is a system which applies for embedded application. This system contains of processor, memory and programmable input output depending on the application usage. For this project, author will focus on using PIC 16F877A type of microcontroller. This device contains 8 bit and 8 channels of Analog to Digital Converter which is suitable for voltage and current measuring [12].

The Analogue to Digital Conversion will be explained detail in chapter 4. This 40 pins device has 5 I/O ports that are suitable for this project as author will include temperature sensing and LCD. Moreover, this microcontroller can be used as a base for the Batter Management System. Figure below is a 40 pins microcontroller.

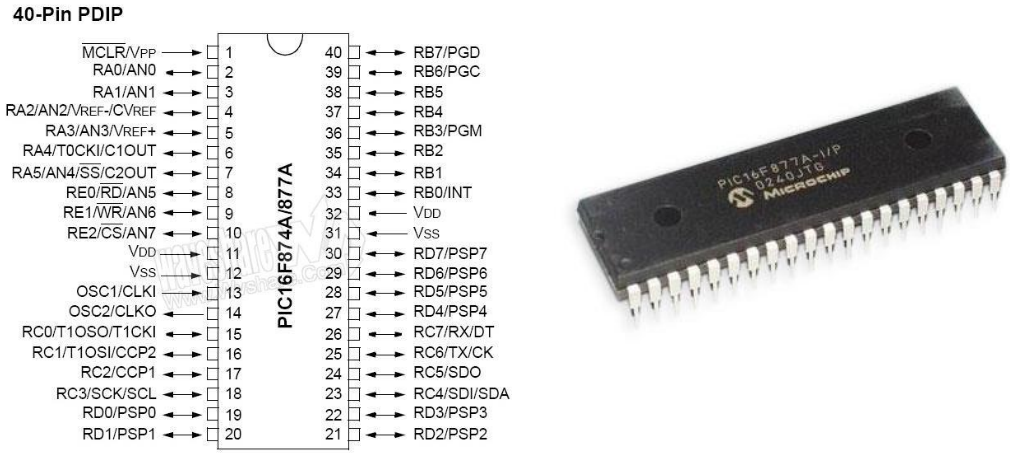

Figure 9: PIC 16F877A Microcontroller

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

In order to achieve the objectives of this project, research and analysis being done on the Lithium Ion Polymer battery using Orion BMS and hardware module testing to determine SOC to be implement on the passive cell balancing prototype.

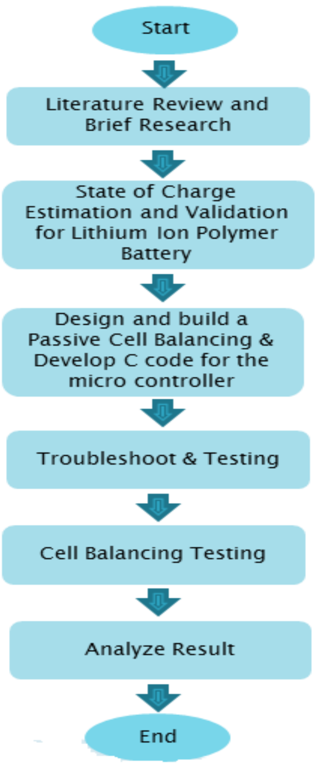

Figure 10: Research Methodology

3.2 Project Development

3.2.1 Orion BMS Setup

The Orion BMS was used to validate the SOC determined using Coulomb Counting. Figure 11 shows the setup of the device connection. The data required was gathered using CAN adapter which integrates with Orion software utility. The connection details diagram for the Orion BMS is shown in Appendix B.

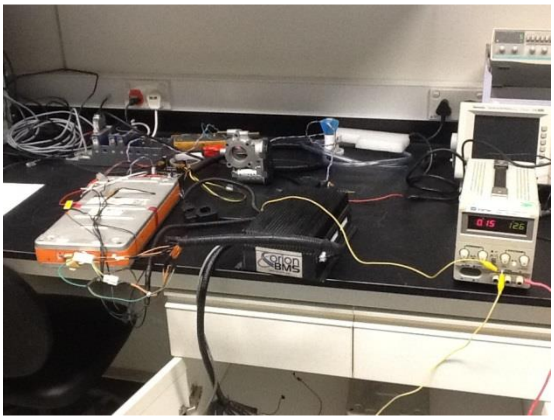

Figure 11: Orion BMS Setup

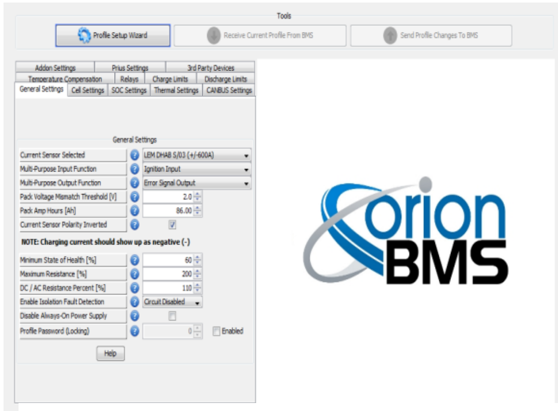

Figure 12: Orion Software Utility

3.2.2 Software development

The first stage of the prototype is on designing the schematic. Eagle Editor Software was used to construct the schematic. Figure 13 and 14 shows the main schematic design of this project and the switching part of this prototype.

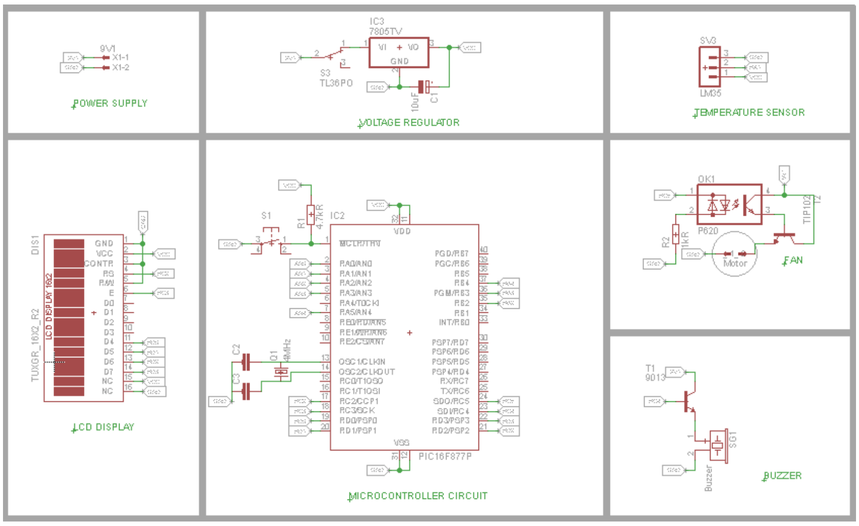

Figure 13: Main Schematic Design

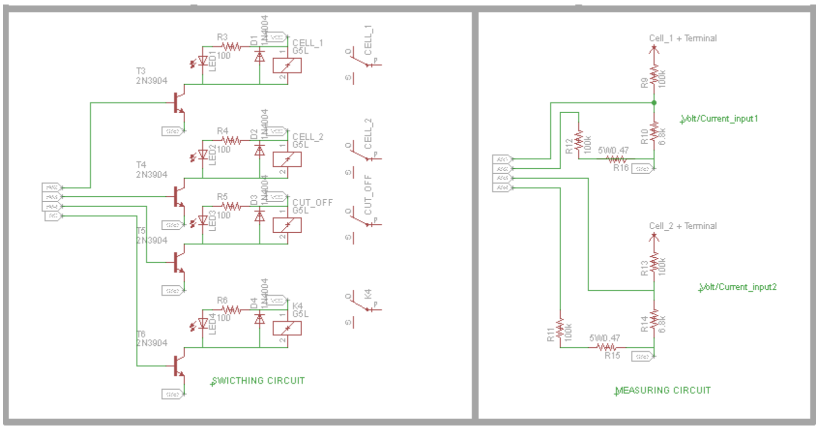

Figure 14: Switching and Measuring Circuit

CCS compiler software was used to develop the source code and the program was tested into Proteus Simulation. Figure 16 shows the simulation design using Proteus. The project was later proceed on designing the PCB Layout as shown in figure 17.

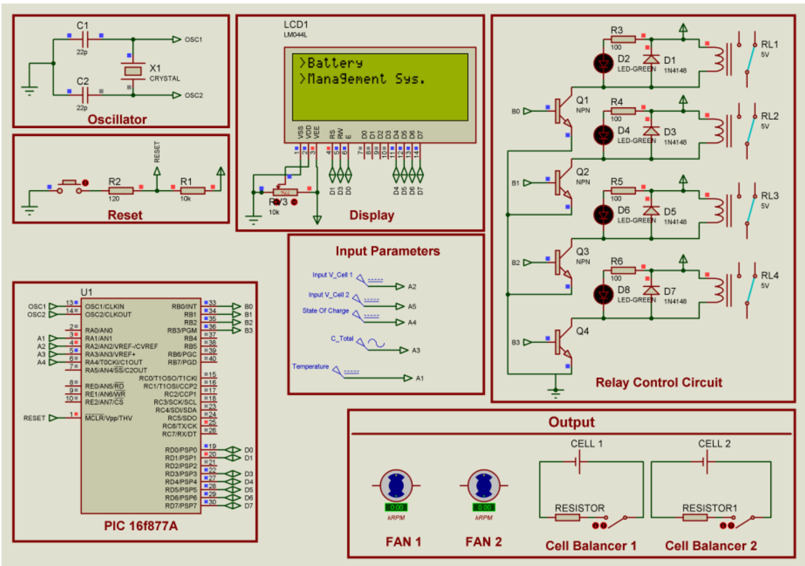

Figure 15: Simulation Schematic using Proteus

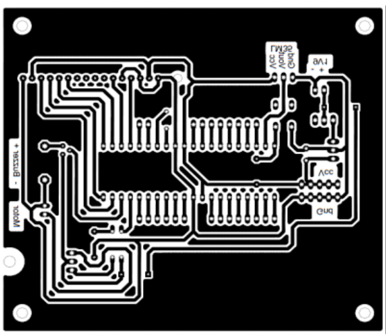

Figure 16: PCB Layout

The source code for C language was develop based on this flow chart. Figure 16 shows the flow sequence desired by the author for this prototype.

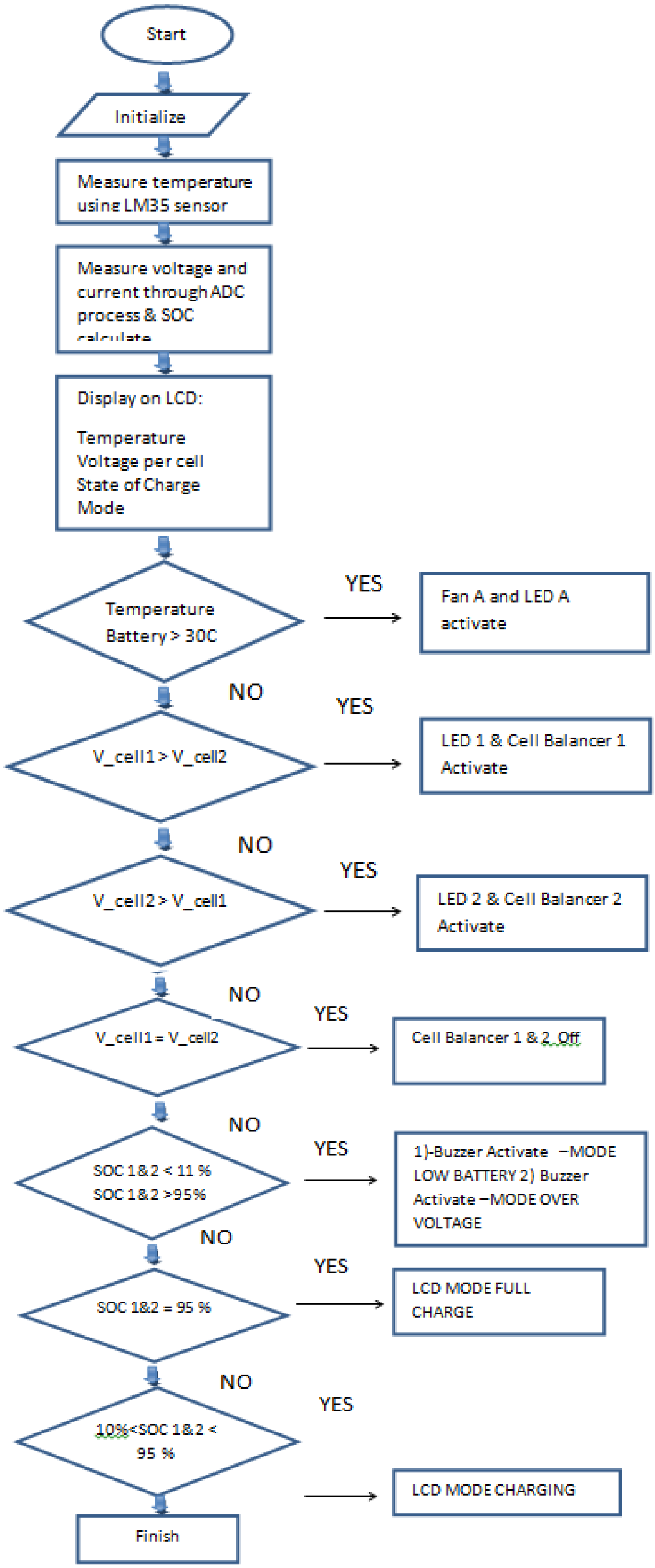

Figure 17: Program Flow Chart

3.2.3 Hardware Development

3.2.3.1 Component Details

Table 3: Component Details

Component Details	**Unit**
Microcontroller PIC16F877A	1
LCD Display 4x20	1
Temperature Sensor LM 35	1
12v DC Fan	1
Relay	4
Variable Resistor and Resistors (1k,10k,4k7)	10
Capacitor (30pf,100nf)	4
Crystal Oscillator (20MHz)	1
9v Adapter	1
LED (Green,Red)	4
Switches	3
Casing	1
PCB Board	2

3.2.3.2 Breadboard and Vera board Testing

Components were assembled on the breadboard and Vera board. Manual testing was done to ensure the circuit works.

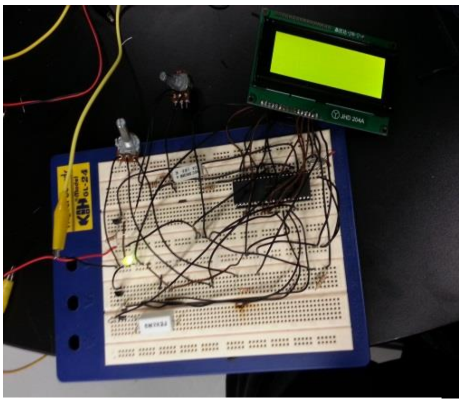

Figure 18: Breadboard Testing

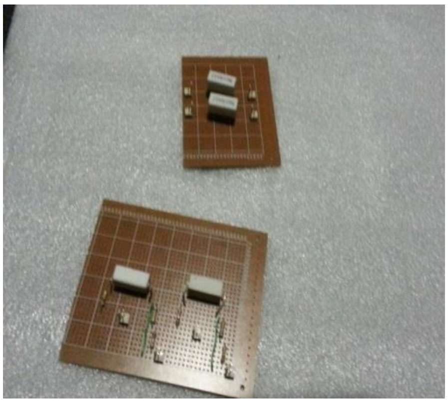

Figure 19: Vera Board Testing

3.3 Tools and Equipment

List below are the following tools and equipment required for completing this semester. Most of the components and tools are available in electrical and electronic lab department.

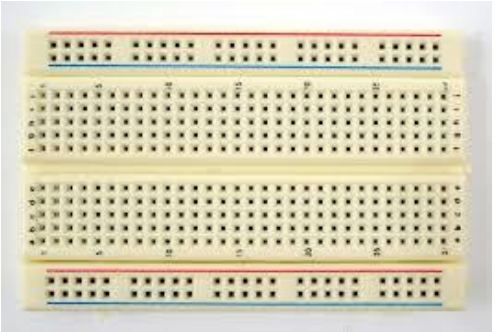

Figure 20: Breadboard

Figure 21: LiPo(1unit)

Figure 22: Power Supply

Figure 23: Hand Tools

3.4 Summary of Project Activities in Gantt Chart

Table 4: Project Activities

Weekly Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Schematic drawing & Program Flow chart															
Listed components required															
Write and Compile Program															
Assemble Components on Breadboard															
Draw schematic for PCB Board															
Progress report preparation and submission															
Project progress and Test Run															
Pre EDX															
Prepare Poster, Final Report															
Draft Report and Final Report Submission															
VIVA															

3.5 Key Milestone Diagram

Table 5: Key Milestone

Weekly Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Schematic drawing & Program Flow chart			■												
Listed components required					■										
Progress report preparation and submission								■							
Write and Compile Program									■						
Assemble Components on Breadboard									■						
Draw schematic for PCB Board									■						
Project progress and Test Run											■				
Pre EDX											■				
Prepare Poster, Final Report												■			
Draft Report and Final Report Submission														■	
VIVA															■

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 SOC Comparison

The SOC profile of Lithium Ion Polymer battery was determined using Coulomb Counting and the result was validate using Orion BMS as shown in figure 24.

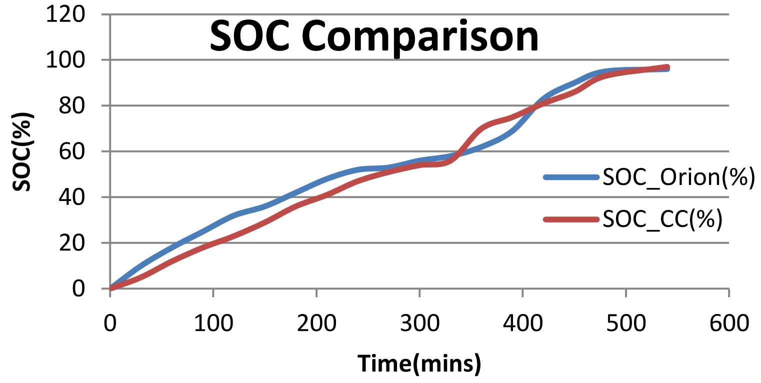

Figure 24: Comparison of SOC Measured using BMS & Coulomb Counting

Table 4: Comparison of SOC

Time/Minut	SOC_Orion(%	SOC_CC(%	Diff_SOC(%
0	0	0	0
30	10	5	4
60	18	12	4
90	25	18	5
120	32	23	4
150	36	29	5
180	42	36	6
210	48	41	6
240	52	47	5
270	53	51	2
300	56	54	-2
330	58	56	-2
360	62	70	-8
390	69	75	-5
420	83	81	7
450	90	86	6
480	95	93	2
540	96	97	-1

Coulomb Counting calculation method was done to determine SOC. It is based on the charging current through the battery. Below is the example formula for Coulomb Counting:

*SOC= [8 Amp * 3 H / 86Ah) x 100]*

SOC= 27.91%

From the observation, there were slight differential SOC (error) between the calculated and measured SOC. Since the Coulomb Counting method only focus on the current flowing in the battery, the results determined is near to linearity. The highest differential is at range 40%- 70% on both SOC, this happen because of the battery characteristic slow increment once it reaches nominal stage. However, the error is acceptable and able to use it in prototype.

4.2 SOC Cells using Coulomb Counting Method

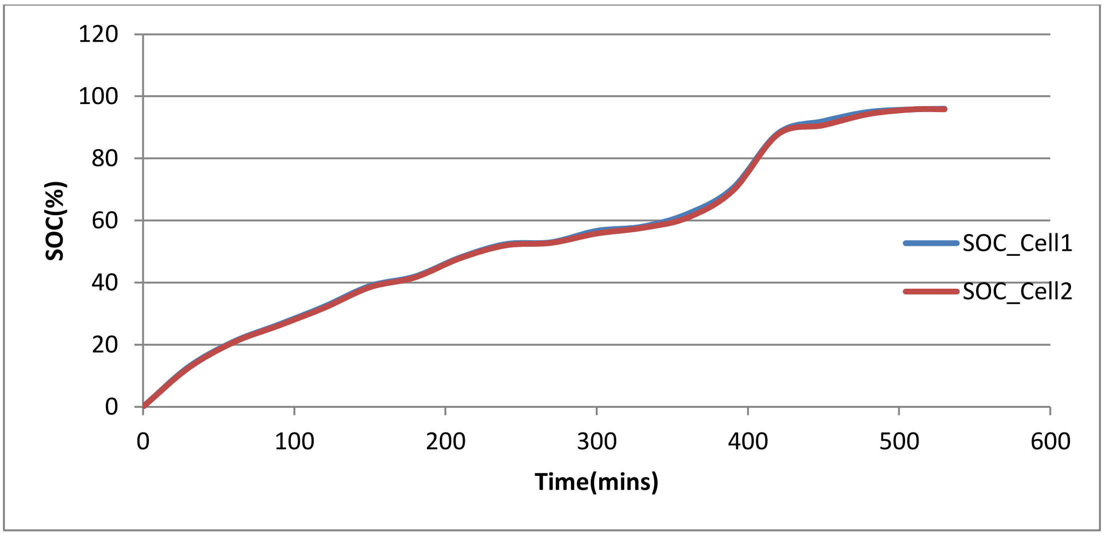

Figure 25: SOC Cells using Coulomb Counting Method

Table 5: SOC Cells using Coulomb Counting Method

Time(Mins)	SOC_Cell1(%)	SOC_Cell2(%)	Error(%)
0	0	0	0
30	12.81	12.76	0.04
60	21	20.8	0.02
90	26.53	26.51	0.02
120	32.33	32.31	0.02
150	38.91	38.88	0.03
180	42	41.97	0.03
210	48.14	48.12	0.02
240	52.41	52.4	0.01
270	53	52.8	0.02
300	56.67	56.66	0.01
330	58	57.98	0.02
360	62.13	62.11	0.02
390	70.42	70.4	0.02
420	88.12	88.1	0.02
450	92	91.98	0.02
480	94.98	94.95	0.03
510	95.8	95.8	0
530	96	95.8	0

Figure 25 and Table 5 describe the SOC of per cell using Coulomb Counting Method. The differential SOC (error) is about 0.02% between Cell 1 and Cell 2. The value is small due to the battery condition which is still new and hardly use. However, author can calculate the current dissipation required by calculating the SOC differences of Cell 1 and Cell 2. Below is the formula used to calculate the current dissipation.

*Idiss = (Diff_SOC * Cell Capacity) / Time desired to balance cells*

Idiss = 0.02 43 Ah/8*

= 108 mA

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

SOC plays an important element in cell balancing. Accuracy on measuring the SOC affects the performance of the LiPo battery. We have established that the manual calculation of SOC was acceptable with slight error compare with the SOC measured using Orion BMS. Thus, this result will be used to determine SOC for the prototype. There were small differential of SOC between cell 1 and cell 2 using Coulomb Counting, this occur because the battery is still new and hardly use. As the prototype is still under progress, the effectiveness of passive cell balancing cannot be determined at the moment. However, the current dissipation for the cell balancing can be calculated as mentioned in the result.

Author plan to complete the passive cell balancing system and further more improve on the design by considering a complete set of batteries. This will give better result and few other parameters need to be considered such as temperature. This test can be implementing in the electric car once the system is ready.

This project provides the first step on enhancing battery utilization technology in electric vehicle. Therefore, the objective of this project has achieved.

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[11] Microchip 16F8xx Family Datasheet.

[12] LM 35 Temperature Sensor Datasheet.

APENDICES

APPENDIX A

Lithium Polymer Battery Specifications

Item	Specification
Weight	≤4.8kg
Normal capacity	86 Ah @ 0.5C
Capacity Range	SOC10 ~ SOC95 (85% Usable)
Normal voltage	(1C) 7.5 V
Charging cut-off voltage	8.30 ± 0.05 V
Discharging cut-off voltage	6.00 ± 0.05 V
Standard charging current	1C
Standard discharging current	1C
Max continuous charging current	172A
Max continuous discharging current	460A @ SOC50, 30sec, 25℃
Max plus discharging current	600 A
Energy density	160 Wh/kg
Power density (SOC50, 10sec, 25°C)	1.813 W/kg
Internal resistance	1.64 mΩ (SOC50, 30sec Discharge)
Charge working temperature	-20 ~ 50℃
Discharge working temperature	-20 ~ 50℃
Storage temperature	-40 ~ 60℃
Appearance	Thickness : 53.6 mm Width : 184.2 mm Length : 360.2 mm As shown in Figure 2

APPENDIX B

Orion BMS Diagram and setup