MEASUREMENT OF POWER FLOW AND STATE OF CHARGE OF LI-ION BATTERY PACK FOR HYBRID/ELECTRICAL VEHICLE APPLICATION

by

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

May 2014

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 being undertaken or done by unspecified sources or persons.

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Muhammad Shafiq bin Samsuni

ABSTRACT

Battery monitoring system is an integral part of Lithium-ion battery pack for hybrid vehicles application can use to monitor and display the output of the battery in good condition, including current, voltage and state-of-charge (SOC). The simulation of this project is to estimate by using current and voltage level employing different algorithm. A circuit will be build consist a shunt resistor to measure the voltage and current, and this variable will ultimately use to provide a measure of SOC. This simulation will be compare with the real data through the test drive of the vehicles. Several SOC calculation method already identified and studies and Coulomb counting is chose to apply through coulomb counting method for SOC estimation. Currently voltage and current transducer have been purchase for the next stage of building the circuit.

Key words – battery monitoring system, SOC and Coulomb counting

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Abstract

Battery monitoring system is an integral part of Lithium-ion battery pack for hybrid vehicles application can used to monitor and display the output of the battery in good condition, including current, voltage and state-of-charge (SOC). The simulation of this project is to estimate the current through chosen algorithm, which is Coulomb counting. A circuit build consist a resistor (load) to measure the voltage and current, and this variable will ultimately use to provide a measure of SOC. The circuit for the discharged experiment was tested and the result of the current will be inserting inside the Coulomb counting formula to get the result for the SOC. This simulation then compared with the real data through the bench lab-test of the discharged experiment.

Key words – battery monitoring system, SOC and Coulomb counting

Chapter 1: Introduction

1.1 Background

Nowadays, the scientist and engineer all around the world seek to invent and upgrade the hybrid vehicle. There are many positive impact rather than negative impact for this vehicle. Due to increase of non-renewable energy price, the vehicle with combination or hybrid of two engines, internal combustion engine (ICE) and electric engine has been developing. This two engine can be overcome each other problem, for example, if the battery run out it can switch to ICE and via versa for the fossil fuel problem. Beside can reduce the cost of buying the fossil fuel, it also can reduce the pollution such as sound and air pollution.

The main component of energy storage device inside the hybrid vehicles is the battery. The battery can be charge-sustaining inside the hybrid electrical vehicles is re-charged by operating machine, either re-generative braking or direct charging through the engine turning function as the generator. Furthermore, to ensure the electric engine of the vehicle receive sufficient energy, the monitoring of output power of the battery is important and must be done such as current flow and voltage levels of the battery pack for the vehicle propulsion.

1.2 Problem Statement

Current flow into and out of the Li-ion energy storage pack needs to be continuously measure and monitored to determine the battery pack's instantaneous state-of-charge (SOC). Along with voltage measurement, several algorithms are possible to determine the SOC of the battery pack in a moving vehicle, with some methods more suitable than the others depending on different factors such as battery type, measurement limitations and accessibility of parameters.

1) SOC battery have to be stable

These signals of power flow and battery SOC need to send to the vehicle's energy management system (EMS) controller. The battery must be in stable position for SOC between 40% to 80% range, which is responsible to ensure efficient and optimized operation of the hybrid electric vehicle.

2) Cell balancing circuit

The charging power of the battery not divided equal with each cells. Therefore, the monitoring for the cell balancing also cover in this project for stabilized the charging power within the battery.

1.3 Objectives

Below are the following objectives and scope of study that use in this project:

1. To identify signal type and range of current and voltage of the Li-ion battery pack and required signal conditioning for interfacing to the vehicle's EMS controller
2. To perform simulation using MATLAB-Simulink on the calculation of current flow, voltage level and battery SOC using different algorithms for comparison and determination of best method for present application.
3. To perform signal connectivity and cabling termination between the EMS, battery management system and battery pack in the hybrid vehicle.
4. To carry out lab-test of the battery power flow and SOC measurement through discharged experiment.

1.4 Scope of Study

There is certain hardware and software can be including in this project. This tool use for circuit built and signal condition from the battery to the transducer for monitoring.

Chapter 2: Literature Review and Theory

2.1 Progression of battery

Apart of the engine, the most important thing in this hybrid car is the battery. Several batteries acknowledged such as lead-acid battery, nickel-metal hydride (NiMH) battery and Lithium-ion (Li-ion) battery. Lead-acid battery produces most toxic, plus it the heaviest in weight matter, which cut down the car efficiencies. While, NiMH battery produce less toxic but carcinogenic, substance that causes cancer. But among these batteries, Li-ion battery is the best to used, because it produces least toxic than the other batteries. In industry, Li-ion batteries already widely use. This lithium element is lighter among other metal and distribute largest energy density [16]. There are many experiments to combine this metal with other metal, but get bad result. Then, they try to research non-metal lithium, element lower than metal lithium. As the result, this battery is safe to use, non-danger to the people and the environment.

The first Lithium-ion battery pack made on 1912, and then continues with development of non-rechargeable Li-ion battery on 1970, which become commercial used all around the world. After that, the first attempt to build the re-chargeable Li-ion battery failed in 1980s due inherent instability along with safety concerns. Unfortunately, there are some limitations of Li-ion batteries such as nee protection circuit, battery is safe if not provoked, easily to aging even if not in used, medium discharge current, expensive to manufacture and other else.

Table 1: Calculated range of a mid-size EV with different batteries of 200L [13]

Technology	Pb-Acid	Ni-C	Ni-MH	Li-Ion
Battery volume allocation (typ.)	200 L			
Module volume allocation	130 L			
Volumetric energy (module) (Wh/L)	75	80	160	190
Onboard energy (kWh)	9.8	10.4	20.8	24.7
Range at 120 Wh/ton/km (km)	81	87	173	206

Table 2: Calculated range of a mid-size EV with different weighing 250kg [13]

Technology	Pb-Acid	Ni-C	Ni-MH	Li-Ion
Battery volume allocation (typ.)	250 kg			
Module weight allocation	195 kg			
Energy density (module) (Wh/kg)	33	45	70	120
Onboard energy (kWh)	6.4	8.8	13.0	23.4
Range at 120 Wh/ton/km (km)	53	73	114	195

The two tables below show the different range in kilometre (KM) for different kind of battery [13]. Thus shows that the Li-ion is produce much power than other batteries that can produce large different of range in the experiment. Based on Nissan Motor Corporation Technology research, this battery provides twice power to the vehicles in same weight and volume [14]. Other hypothesis, on the table below, said the more weight of the battery, the more energy it can supply. Therefore, it will become insupportable with the vehicles [13].

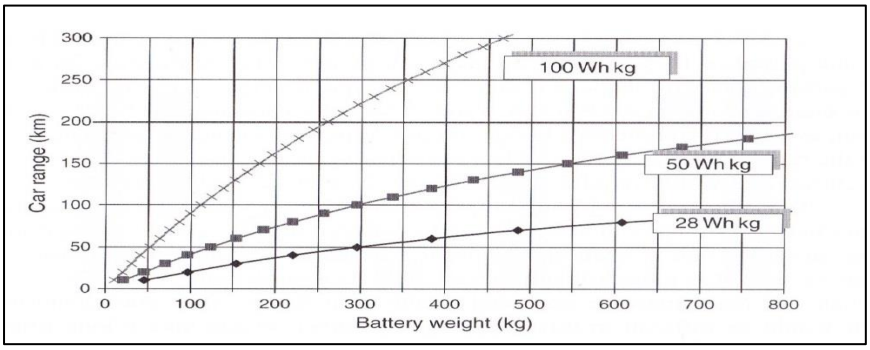


Fig.1: Calculated car range as a function of the weight of batteries with different specific energies. [13]

For the vehicles to boost or accelerate, it required the energy from the battery. This situation also applies while braking. Therefore, in order to get the good efficiency, the battery must need suitable state-of-charge (SOC). SOC is battery capacity that has inside the battery, which measured in term of percentage [18]. This SOC also related with aging of the battery. Even though each time the battery fully charges of the battery, the real value that the battery owns only get is 90% from 100% of the charge. It might not happen directly, but from time to time, the battery become useless, for example, the laptop’s battery. The capacity will be empty cause always fully charge for several year.

There are several methods to recharge the battery for the vehicles. One of the methods is through generative braking system [19]. When the vehicles is braking, all the kinetic energy become slow down, while the electrical engine become generator at some frequencies. Moreover, the computer on-board stop sending the electricity from the battery and start sending signal to the charger to charge the battery. Other than that, the engine itself also can direct charging the battery as generator that generate charge then fill it in the battery.

In order for the batteries receive the recharge energy form the generator, it required enough headroom in the battery. For the simple analogy, if the pail already full of water use it or take out some water, before fill with the new water. This same goes in the battery; it needs some space or enough energy to receive the recharge energy to operate.

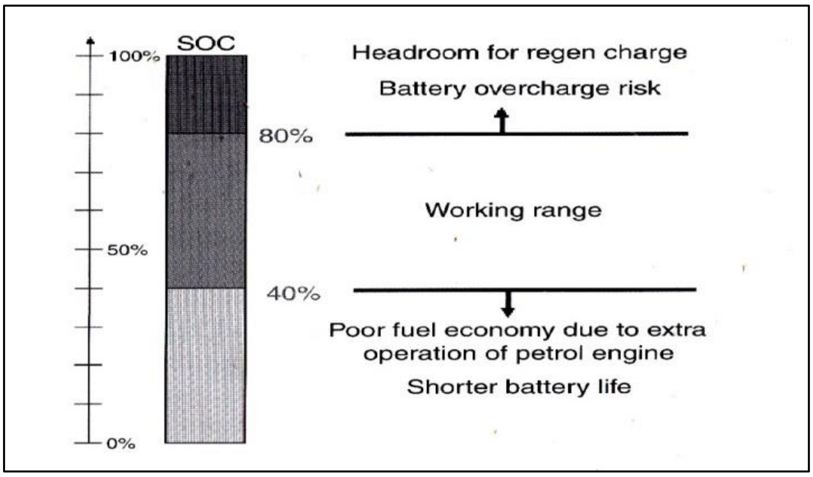


Fig.2: Battery SOC and performance [13]

The above figure show that the state-of-charge of the battery. The range 40% to 80% is good for the working range. This is because while in this range, the internal resistance inside the battery are lower. If the SOC over 80%, high depth of discharge (DOD) will occurs [13]. Other reason, because the generative energy from the braking will fill up the space without overcharging it and overcome the overflow of the battery.

Apart of the higher limit, there also lower limit set, 0% to 40% [13]. It shows the battery already in the weak condition. If the battery still used continuously, it may be harm the battery and shorten the battery life. This limit also set up to prevent the vehicles consumes much fuel than normal rate.

2.2 Measurement

Some measurements can be taking from this battery. The important measurement is voltage, current, and state-of charge. The voltage is force of the moving electron [6]. The electron cannot jump from atom to another atom without some push or force. Therefore, with the help of the pushing force, electron can flow to entire circuit. From that, the voltage can obtain. For the voltage measurement, the device must put in parallel to the circuit; otherwise, the voltage reading cannot be taking. Based on Ohm's law, if the resistance of the battery low, while the current remains constant, the voltage will be high.

As the result from the moving electron by the pushing force, there will be current [6]. The current is measurement of flow rate of the moving electron. Nevertheless, for voltage and current, their flow will be opposite. For measurement of the current, the device must put in series with the circuit. While the voltage remain unchanged based on Ohm's law, the current will be high if the resistance is low.

As for state-of-charge, the measurement is in percentage. Therefore, some device needed to display the percentage of the battery, because the SOC did not count by ohm, ampere even the volt.

2.3 Mathematical Calculation / Methods

The SOC is measure by using percentage. The mathematical calculation need to apply for this experiment in order to find the SOC of the battery. The parameter include such as current, voltage, temperature and other information that related with the mathematical equation [12].

1) Voltage based measurement

This method considered simple because, if the SOC of the battery decrease, the voltage also decreases. This method applies for the other battery but not the Li-ion battery due to voltage profile of the Li-ion chemistry. This method provides good measure of cut-off point for the battery due charge and respectively discharging [1]. The Li-ion battery can use this method with other additional method because relying on this method only; it could lead to miscalculation and high inaccuracy of estimation SOC.

2) Coulomb counting method

This equation use to estimate the SOC using current. The input current will integrate; to determine the capacity of battery [1]. For the equation below for example, based on the reference capacity, 20 Ah, the current integrated to determine the value of the SOC.

$$\text{SOC [\%]} = \frac{20-\int_{t_0}^{t_0-T} i\,(t)\,dt}{20} \text{ x } 100 \qquad [1]$$

There are several problem will be face if this method were used. The first one will be problem with the integrator. If the integrator not restored the reference value continuously, which mean the value for the battery capacity, the result might be different every time the method was used [14]. Secondly, it will be problem cause by degradation of the battery between fully charging, maybe too small or large in the small cycle cause an inaccurate other parameter such as current measurement and compensation [1]. However, these problems only result if the vehicle used is normal car with combustion engine. The hybrid vehicle usually is charge at night and the SOC value will restored as usual for the integrator. The old value of the battery that used will removed.

$$\text{Coulomb Efficiency} = \frac{Discharged\ energy}{Charged\ energy} \qquad [1]$$

Coulombic efficiency related with charge and discharge energy. For SOC's calculation, the efficiency needs to be keeping in mind every time. There is more power that needed to charge the battery for the power to deliver, that will be loss during the discharge such as losses inside the cell. Other parameters that also will affect are current rate, temperature and SOC. As the solution for this problem, the battery need to carefully measure and record the battery current SOC in the laboratory environment with different kind of conditions in order to support the accuracy estimation [1].

3) Modified Coulomb Counting

To improve the Coulomb Counting formula estimation, the previous formula modified with using the corrected current, as function of discharging current. The quadratic formula of modification is relation between corrected current and discharging current of the battery. The corrected current can calculate by using following form:

$$I_C(t) = k_2 I\ (t)^2 + k_1 I\ (t) + k_0\ , [1]$$

where k_2 , k_1 and k_0 are constant values obtained from the practice experimental data. So, from the corrected current equation, the Coulomb counting equation modified by following form:

$$SOC\ (t) = SOC\ (t-1) + \frac{I_C(t)}{Q_n}\ \Delta t.\ [1]$$

Where $Q_n$charge is stored of the fully charged battery in ampere-hours (Ah) unit and Δt is differential sampling period. By this modification, the accuracy of the Coulomb counting will increase rather than used the conventional Coulomb counting method. It most suitable to use in the experiment which inaccuracy commonly happened.

4) BP Neural Network

This method is the most popular but complicated for calculating SOC percentage because due to the ability of nonlinear mapping, self-organization and self-learning [1]. For using this method, the recent history of voltage, current, and ambient temperature of the battery also need to take.

In the figure below, the Neural Network contains three layers: input layer, output layer and hidden layer. Inside the input layer contains three neurons: terminal voltage, discharge current and temperature, while in hidden layer contain g neurons and output layer contains only one neurons: SOC neurons [1].

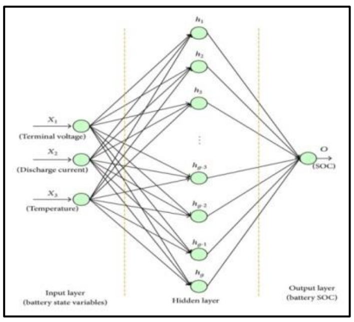


Fig.3: BP neural network: the architecture of the SOC [1]

Inside the hidden layer, there is formula to calculate total input of neurons:

$$neti_j = \sum_{i=1}^{3} x_i v_{ij} + b_j \text{ , [1]}$$

where $neti_j$ is total input of the hidden layer neurons j; x_i is input to the hidden layer neuron j from input layer neuron i; v_{ij} is weight between the input layer neuron hidden layer neuron j and i.

The following equation is hyperbolic tangent function that applied for activation in hidden layer:

$$, h_j = f(neti_j) = \frac{1 - e^{-2neti_j}}{1 + e^{-2neti_j}} \text{ [1]}$$

The total input of the neurons o in output layer is calculate by

$$net\ o = \sum_{i=1}^{g} h_i w_i + k \text{ , [1]}$$

where net o is total input of the output layer neuron o; h_i is input to the output layer neurons form hidden layer neuron i; w_i is weight between the hidden layer neuron i an output layer neuron; k is bias of the output layer neuron o; g is number of neurons in the hidden layer.

The activation function applied to neurons o in output layer is the sigmoid function as the following equation:

$$o = f\ (net\ o) = \frac{1}{1 + e^{-\ net\ o}} \text{ . [1]}$$

5) Kalman Filter

These methods show to estimate the SOC reading of lithium-ion battery. The result of experiment validate when using the online applications. It provides verifiable estimations of SOC of the battery via real-time state estimation rather using the real-time measurement road data that normally is difficult or expensive to measure.

Below is Kalman filter's equation:

$$\hat{Z}_k = K_k \,.\, Z_k + (1 - K_k) \,.\, \hat{Z}_{k-1} \text{ , [1]}$$

where $\hat{Z}_k$ is current estimation; K_k is Kalman Gain, Z_k is measured value and $\hat{Z}_{k-1}$ is previous estimation. In this equation, the only unknown component is Kalman Gain, K_k. This gain need to calculate for each consequent state because the measurement value and previous estimated signal already given [1].

6) SOC Drift

This method is open-voltage map that required monitoring of the battery while charging and discharging. It's the same method as the voltage method, but it can produce high accuracy of the battery measurement while in operations [2]. However, this method needed accurate calculation of battery capacity and it need to know in order to define fully SOC.

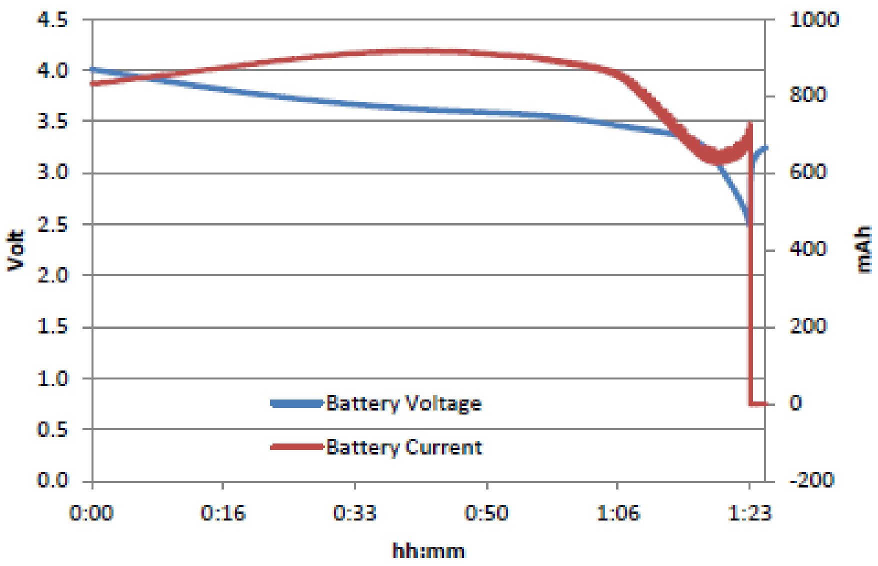


Fig.4: Coulomb counting & SOC drift [2]

The graph 2 shows that the Coulomb counting (red line) and SOC drift (blue line). These two methods is most suitable measurement of state of charge since the measurement need to take during the operation of test drive.

2.4 Charging and Discharging Cycles

Before doing the charge and discharge cycle, some important points need to take. One of the points is required charge termination for either the end of charge current or cell/pack temperature that usually carried out by monitoring [15]. If the cycle carried with unofficial charger, the extra external charger is recommending. Other than that, the safety protection for the batteries also will be needed [15]. If there are some short circuits or current fluctuation happens, the circuit will protect the charger and batteries from damage.

The research for the charging and discharging cycle rely based on the previous experiment on this cycle. For the Lithium Polymer cell that has 3.7 V with maximum charge current is 1 A and maximum discharge current is 2 A [15]. The graph from this experiment is show below.

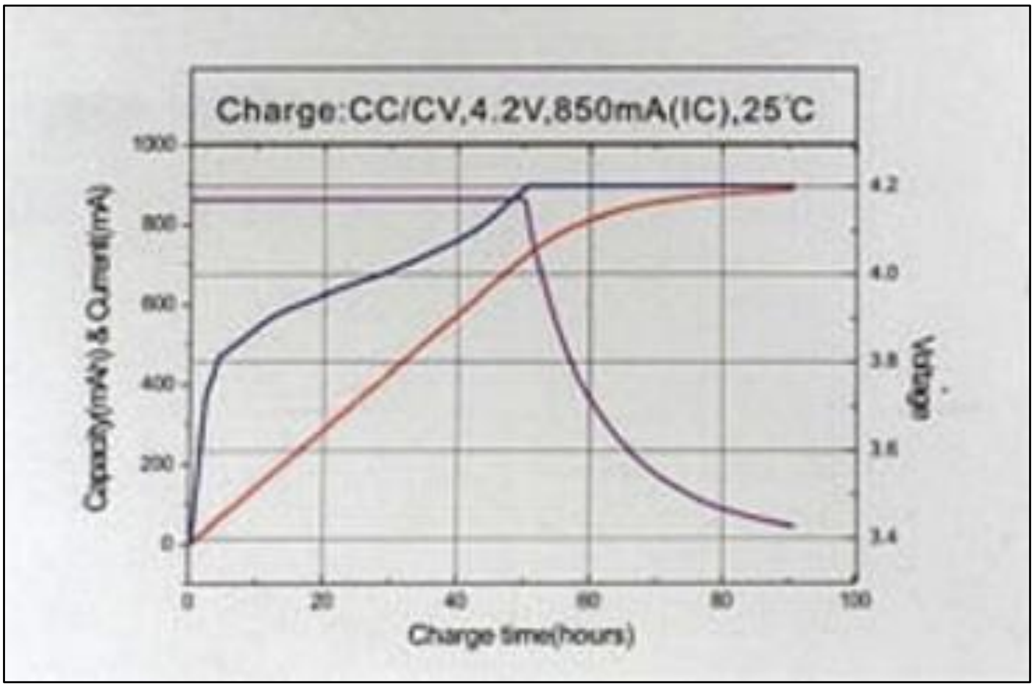


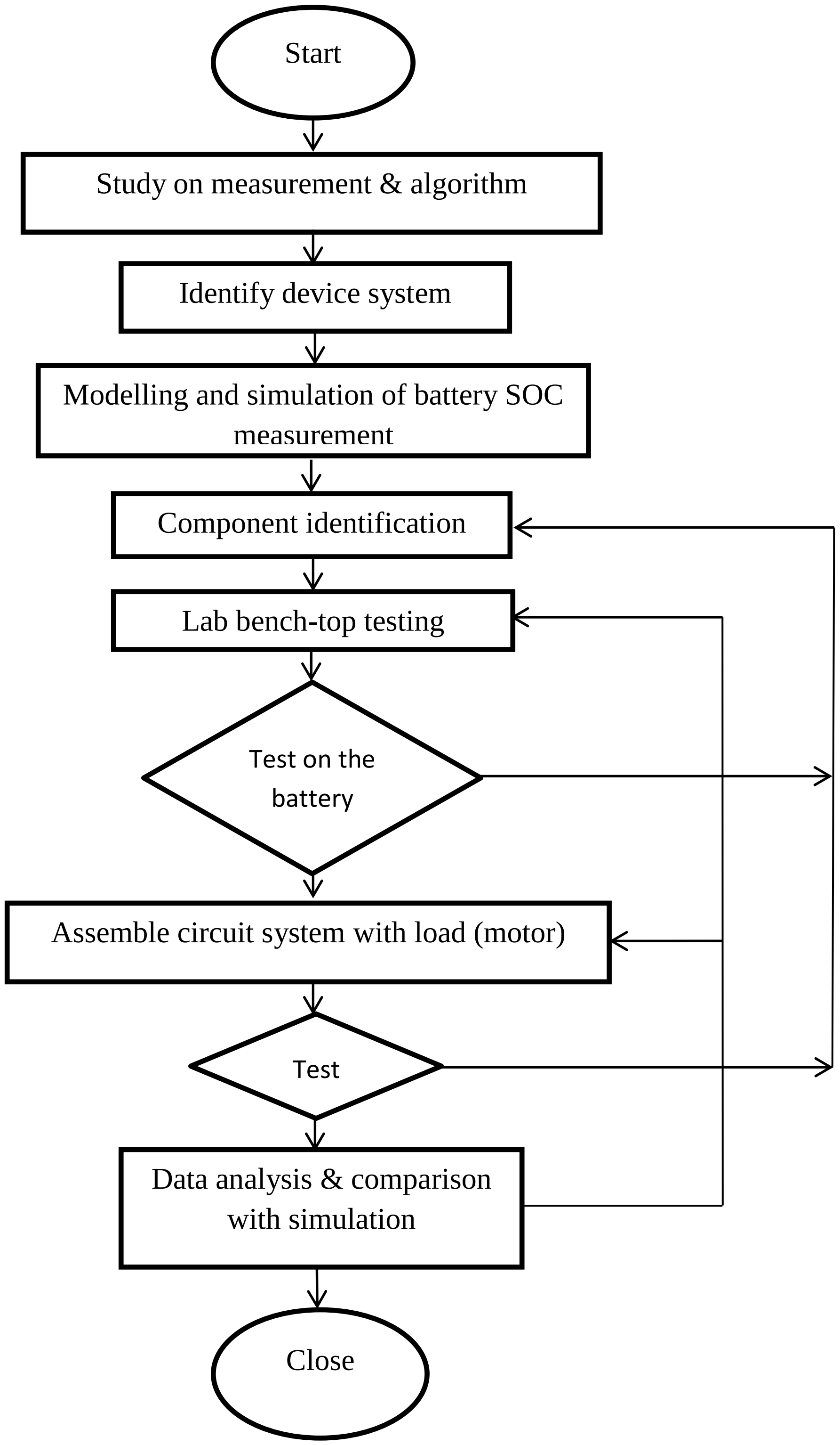
Fig.5: LiPo Charge & Discharge Graph [15]

The charging cycle (red line) is increases proportionally during the experiment. As expected, the voltage (blue line) also increase until certain time (hours), and the graph constant. This is because the voltage required of the batteries already at fully charge. For the current graph (violet line), as the voltage increases, the current slowly decreases same as the real capacity of the batteries.

These are several method as describe above can be used to calculate or measure the SOC. Nevertheless, among the methods, the Coulomb counting is more compatible and suitable for the discharge experiment because it showed decreasing in graph or calculation. Furthermore, the data taken in the experiment also can apply directly into the equation to calculate the SOC. In additional, there is certain accuracy in calculation needed in several methods, which is more complicated than the Coulomb counting.

Chapter 3: Methodology/ Project Work

3.1 Flow Chart



3.1.1 Background and literature review of battery characteristic

The flow chart shown above is about the flow of project from FYP1 until FYP2. The important matter is to understand about the characteristic about the battery. There are several types of battery with different type of characteristics. Furthermore, the state-of-charge (SOC) and level of SOC of the battery need to be understanding more for advantages that can give to the vehicles.

3.1.2 Devices with working conditions and software

Apart known the characteristic of battery, the device that make the project work also need to know. There are several devices that can use in this project from different aspects such as what kind display that these devices can do or measure, what maximum voltages or current that this device can measure and other else. Moreover, the circuit connect from this device to the batteries also need to study before the circuit is tested. Beside the hardware, the software also will use in this project. The software is using to design the circuit from the battery to the Electrical Monitoring System (EMS) or to the other devices. Beside the software to design, other software also needed to use for the simulation of the battery to predict result before assemble the real battery circuit.

There is also simulation based on the Coulomb counting method. The flow of the calculation made up in the block diagram and the output of the calculation directly showed in the scope.

3.1.3 Circuit design and assembly

Before the circuit build up, the circuit must be design first. The devices that need to be use must consider based on the cost and sensitivity. It might produce wrong data if the devices less sensitive and need to repeat all over again. In addition, the devices need to be use with suitable component, which might found in correct datasheet. All circuit design also need to be specified and suitable with the certain condition. For example, if the battery's voltage is too high, the suitable device must use to prevent it from burst. To complete testing of the circuit, the load that is the motor will be directly connect to the battery for the discharging experiment.

Unfortunately, for the experiment, one of the Li-ion batteries already burst out during the charging. Therefore, as the initiative of the experiment, the Li-ion battery exchange with the lead-acid battery. In additional, the charging experiment cannot do alone because need authorities to monitor or supervise for the charging experiment before the same incident happens again. Other than that, the vehicle for this experiment also still in configuration at the workshop, so the bench lab-test have been exchange for this study. The scopes of the experiment also become smaller than the real test. Therefore the resistor (load) is stand for the electrical motor on the vehicles and two out of five lead acid battery use for this experiment. The figure below is the setup circuit for the discharged experiment.

Fig.14: Circuit of the discharge experiment

3.1.4 Data analysis and comparison

There is range of data taken in some period in this experiment. This is because of the discharging of the battery will take long time. From the data, the graph will be plotted and analyse. Then, the comparison from the simulation graph with the experiment graph will be take part. From the comparison, the percentage error will calculate in the same point of time due to the gradient.

3.2 Gantt Chart and Milestone Planning

No.	Activities	Weeks													
	FYP 1 Progress and Milestone (Jan 2014)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title Selection														
2	Preliminary Research & Literature Review														
3	Components Identification & Evaluation														
4	Circuit Integration and Assembly														
5	Lab Experiment / Simulation Project														
6	Extended Proposal														
7	Proposal Defend														
8	Preparing Interim Draft Report														
9	Preparing Interim Final Report														
	FYP 2 Progress and Milestone (May 2014)														
1	Circuit Assembly / Simulation Project														
3	Thesis/Report														
4	Project Viva														

3.3 Hardware and Software

3.3.1 Hardware

In this project, the hardware that needs to use is National Instruments' CompactRIO real-time controller or with the simple name is Energy Management System (EMS). This hardware is to collect data from the components inside the vehicles such from the generator, braking system, battery management or other else. With this component, the device that chose will connect and display data on it. Reconfiguration of embedded control and acquisition system is offer by this devices for retrofit conversion hybrid electric vehicle and suitable to be used for EMS. This is because it has very flexible and complex hardware architecture, which allows user to choose and configure variety of I/O modules not only from National Instrument but also from third party. In term of programming, National Instrument's Labview well known to be designed this CompactRIO.

Fig.6: CompactRIO Real-Time Controller

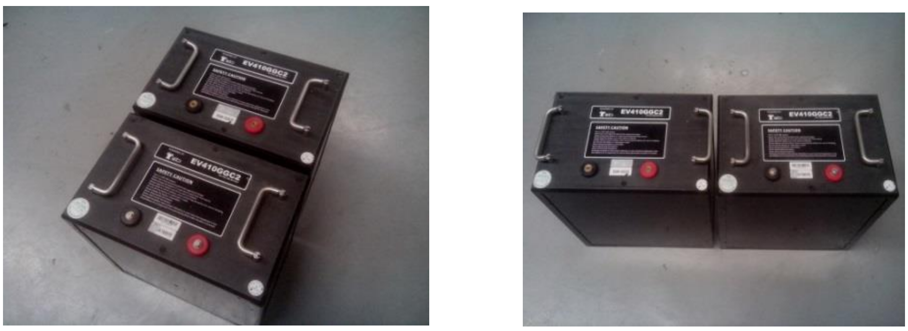


Fig.7: Li-ion batteries (52 Volts)

Table 3: Specification of the Li-ion batteries [3]

Technical Specification (Batteries)	Rate
Nominal Voltage	52 V DC
Capacity	40 Ah
Dimension	L325 x W205 x H327 mm
Charging Current	20 A (maximum)
Charging Voltage	58.8 V (maximum)
Maximum Continuous Discharge Rate	40 A
Output Voltage	42 V – 58.8 V
Operating Temperature	-20°C - 55°C
Peak Output Current	80 A (limited by circuit @ 20 millisecond)
Splash Proof	Yes

Fig.8: Batteries charger (DCS 60-50E)

Table 4: Specification for batteries charger [4]

Models	SORENSEN (DCS 60-50E)
Output Ratings - Output Voltage - Output Current - Output Power	 0 – 60 V 0 – 50 V 3000 W
Line Regulation - Voltage - Current	 60 mV 50 mV
Meter Accuracy - Voltage - Current	 0.7 V 0.6 V
OVP Adjustment Range	3 – 66 V
Output Noise and Ripple (V) - RMS - p – p (20 Hz – 20 MHz)	 20 mV 100 mV
Analogue Programming Linearity - Voltage - Current	 600 mV 500 mA

The pictures below showed brushless DC motor. This motor used as the load for the battery to charge and discharge experiment as well as its spec for the simulation. The power to move this motor is 7kW with 72V of battery.

Fig.9: Kelly's car hub motor 72V 7kW

3.3.1.1 PakTraker

There are many devices that use to measure voltage, current, and SOC. One of the devices is PakTraker (PT), a device that converts physical quantity to electric signal. This device can measure 4 to 6 batteries in a row with one remote while display individual batteries voltage in one time [7]. This device has a 250A fuse that is fast-blow and located in shrink tubing at ring terminal on the black wire. In additional, the current draw without the PT display will be 4mA or with the display 9mA. For the other batteries, the current draw will be not more than 1mA. The other functions or display of the PT is SOC of battery, Amperes or Watts, 30-day logged data, and text alert for failure or warning conditions.

3.3.1.2 Fuel Gauge

Other than that is fuel gauge. It uses the same principle to measure the fuel in the tank. Therefore, based on the fuel gauge, it can estimate the SOC of the battery by analogue meter. If every day the battery used, the pointer in the fuel gauge will show at red location or empty. However, this device has disadvantages. For the battery, it not like the energy container, always flow out the energy to use. It has more complex electrochemical to dissolve to produce electricity [8]. Other than that, this fuel gauge did not show the aging of the battery. It might be troublesome for the future if it did not do frequently check the battery.

3.3.1.3 Intelligent Integrated Battery Sensor

Moreover, another device that measure SOC is Intelligent Integrated Battery Sensor (IIBS) by Freescale Semiconductor. This small chip also made to measure voltage directly by series resistor to the battery or current via external shunt resistor [9]. Besides that, this chip also can measure temperature of the battery, have accurate internal oscillator, signal low-pass filtering and other else. Therefore, the circuit need to build for this chip for monitoring system based on the datasheet given by this company.

3.3.1.4 Carbon Pile

In addition, carbon pile also can use to measure the SOC of battery. This device is use in worldwide industry since 1980s. It can also measure the voltage and current of the battery. To check the current flow, it applies a brief direct current (DC) load. The battery must be fully charge before begin the test. Nevertheless, to pass the test, the battery must not fall below 9.6V of 10° and higher [10]. However, for the disadvantages of this device, before the tests begin, it must have full SOC. Besides that, this device is not suitable to install inside the vehicles cause it too big.

3.3.1.5 Current Clamp

The transducer is a device that can transform energy from one form into the others. As the current transducer, it transforms the current, whether alternating current (AC) or direct current (DC), from the circuit into the digital input. Furthermore, the shape of this transducer is like a ‘donut’, because it applies on the theory of Hall Effect [17]. This theory applies in the circuit, which transverse electric current in conductor produce a magnetic field that perpendicular to the current [21]. The charge of the current that being measure will depend on the type, number and properties of the charge carriers that constitutes the current.

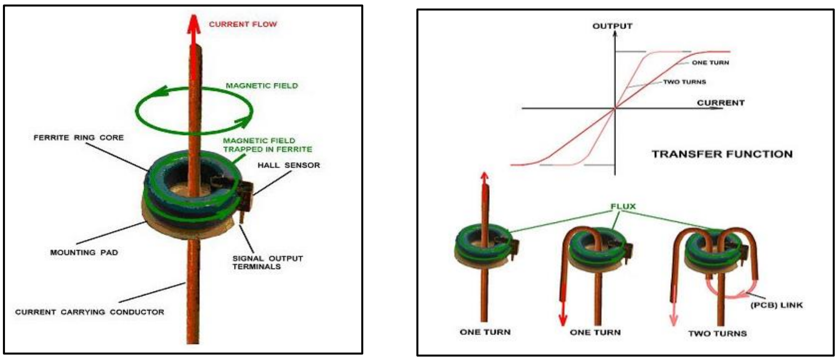


Fig.10: Effect of conductor passes through core of current transducer [21]

There are also device that applied this Hall Effect theory. One of the devices is current clamp. This device use to take the value of the current inside the complete circuit. It easy to use because no need to add or put any component in series of the circuit, just clamp the wire and the value of the current will appear on the devices.

Fig.11: Current clamp

As the hardware, describe above for the device to use in monitoring the SOC, the current clamp chosen. This is because, the Coulomb counting used in this experiment use the current to calculate. Therefore, the current clamp will take the current directly from the circuit into the database. This is easier method to take the data rather than complex device's method.

3.3.2 Software

For the circuit build, the software that used is Pspice. There are many component that needed in this project is available in the software. For the simple way, a simple circuit was build using the basic component such as resistance, switch, and battery. After that, the complex circuit modified based on the simple circuit by added up the motor, the motor controller and other else. This design of circuit will be as reference for build the real circuit in the laboratory for bench testing.

Chapter 4: Results and Discussion

For discussion in this project, the shunt circuit use to identify the current and voltage. To determine SOC of the battery, the current and voltage of battery need to identify. Before searching the variables, the charging the battery need to be adjust.

Capacity of the batteries: 40 Ah

Current that needs use in charging: 20 A

Hours batteries complete charging: $\frac{40\ Ah}{20\ A}$ = 2 hours

Two hours needed to charge the batteries, if there are no losses during the charging cycle. Therefore, if the current for charging cycle is low, thus more than two hours needed to do this charging.

Based on the graph below, the amount of current (charging cycle) enter the battery, the voltage give the respond corresponding to the current. This graph also illustrate that the ‘danger zone’ (top right corner), which charging with high voltage and high current at same time would damage the batteries. To avoid it happens, one tenth of battery capacity needed to use for current when charging [11]. Therefore, for this project, the response needed to make sure between both of the variable is corresponding or not.

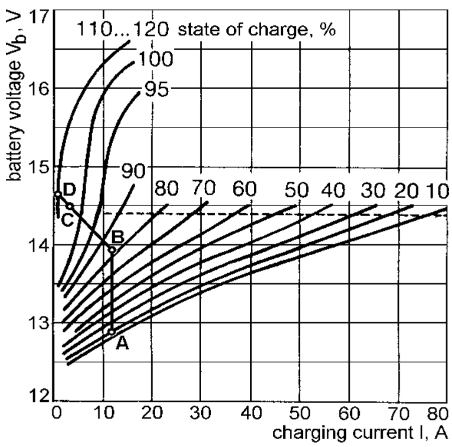


Fig.12: Relation between charging current, voltage and state of charge [11]

A shunt is a method that allows electric current to pass around another point in the circuit by creating a los resistance path. The voltage drop across the shunt can scaled to direct display the current value. The schematic showed which shunt circuit apply to perform the Coulomb counting. V_{batt} is actual battery voltage and V_{shunt} is the voltage that drops across the shunt resistor [2]. The value of the current flows in or out will calculate by dividing V_{shunt} with R_{shunt} value. For the resistance value, R_{shunt}, inside the shunt circuit still need to measure or change to suitable with voltage carried because it might be high and for safety of the CompactRIO [2].

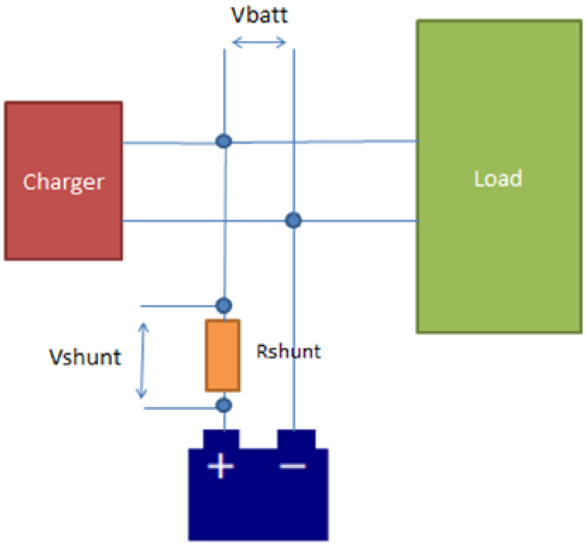


Fig.13: Schematic to perform coulomb counting [2]

4.1 Discharge Experiment

As for the result of the experiment, the time taken based on the real time. The battery that used in this experiment is lead-acid because it has not much different between Li-ion batteries in term of characteristic. Other than that, there some technical problem that faced as before one of the Li-ion already burst. Therefore, as other initiative, the lead-acid battery is being used because of it condition still good. The fully charge of two lead-acid battery is 22V. Nevertheless, in this experiment, it takes too long time for the battery to drain, so manage to take the reading for every 5 minute. The result of the experiment can be look on the **Appendices A**.

For this experiment, the battery connected to the load exchange as the DC motor, which is the 2-ohm (Ω) resistor in parallel. The resistor connected in the form of parallel because as the resistance smaller, the voltage will become higher as well as the distribution current. The switch connected between the battery and resistor before the experiment start for the safety reason. For the measurement, current clamp already purchased. This device use based on the method that already agrees, through Coulomb counting and SOC drift. Several preliminary works need to take such as in charging and discharging cycle, the voltage level map and current level map is very important. This value next will use in simulation of MATLAB.

As soon as the experiment started, the voltage reading on the battery is taking. At the same time, the voltage that passes through the resistor also taken. The current of the battery can calculate through the Ohm's law, by using the value for the resistor. After that, the current convert into the Amp-Hours unit, is integrated by the area of each calculated current multiplied by the times, which is one minutes. The total Amp-Hours calculated from the summation or cumulative of the Amp-Hour distribute by the battery. As for that, the graph below showed the result of this experiment:

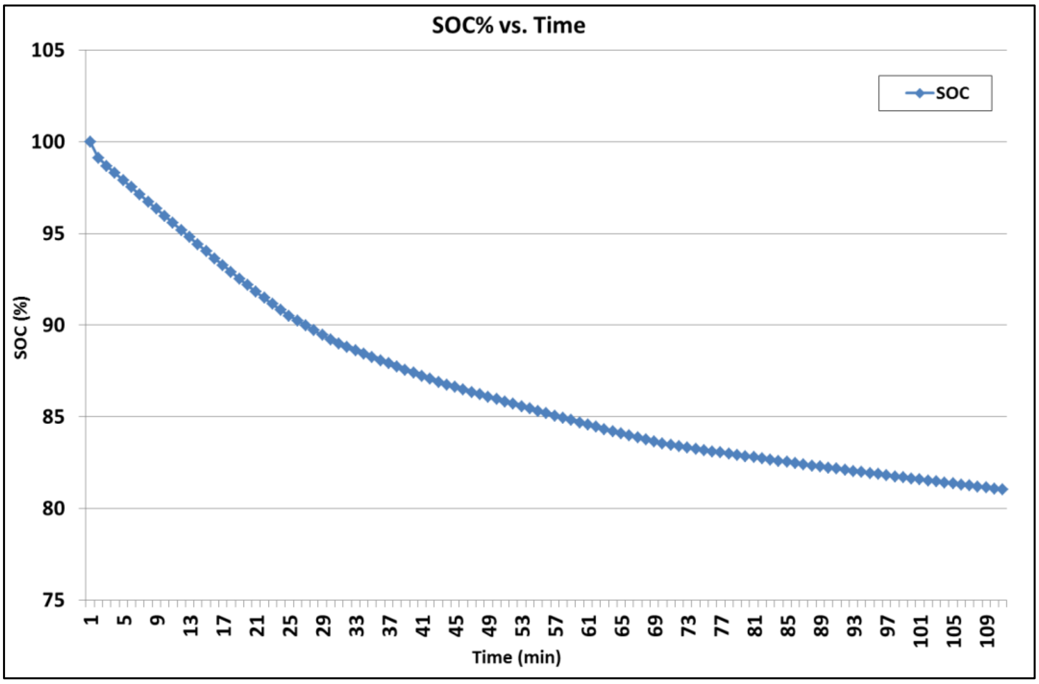


Fig.15: SOC (%) vs. time

The graph show decreases of SOC of the battery. After several hours, the battery empties as well as the SOC. The gradient might not exponentially decrease because of some mistake or human error during taking the value of the voltage. Other than that, the component or material that use already ages for example the battery or resistors.

4.2 Simulation

4.2.1 Brushless DC motor simulation

For the simulation, this project used the Simulink in the MATLAB. The battery connected to the brushless DC motor by adjusting the power source for the port voltage from three ports to the two ports for positive and negative poles of the batteries. Other than that, the brushless motor need to be having input from the speed to the SP port and torque to the Tm port for the motor started.

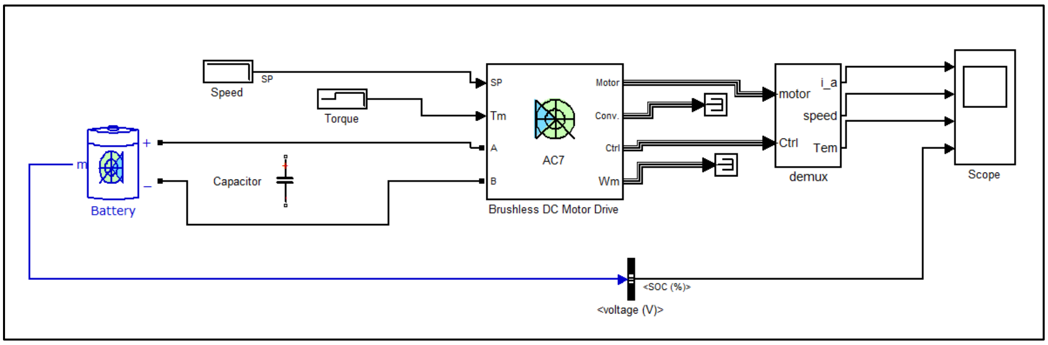


Fig.16: Discharge Simulation of MATLAB

The purpose of the simulation is to know how long the time taken will use for the battery to drain. As for that, it takes almost 2 hours for the battery's power to drain. In the graph shown below, for small amount of time, which is 10 minutes, it only drain small amount of power. This proves that the battery will be last for long period if fully charged. However, this does not mean that the battery can last longer for several of year, because each time the battery is fully charged, the amount of SOC will be decrease until the battery cannot used.

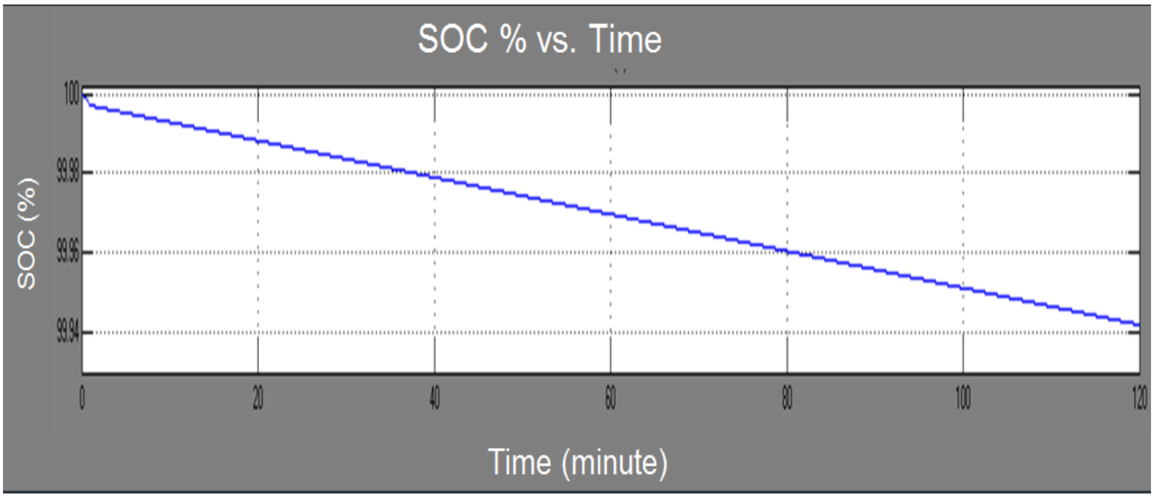


Fig.17: SOC discharged simulation in 120 minutes

The graph for the simulation has smooth decreasing in gradient. This is because there are no interruption in the simulation such vibration and other else. The decreasing for the SOC of the battery is small because the resistance's load in the simulation not large, so the current distribution for the battery larger than the expected.

4.2.2 Coulomb counting Equation Simulation

This simulation based on the Coulomb counting equation. The flow of the calculation made up on the Simulink via block diagram. The figure below showed how the configuration of this simulation.

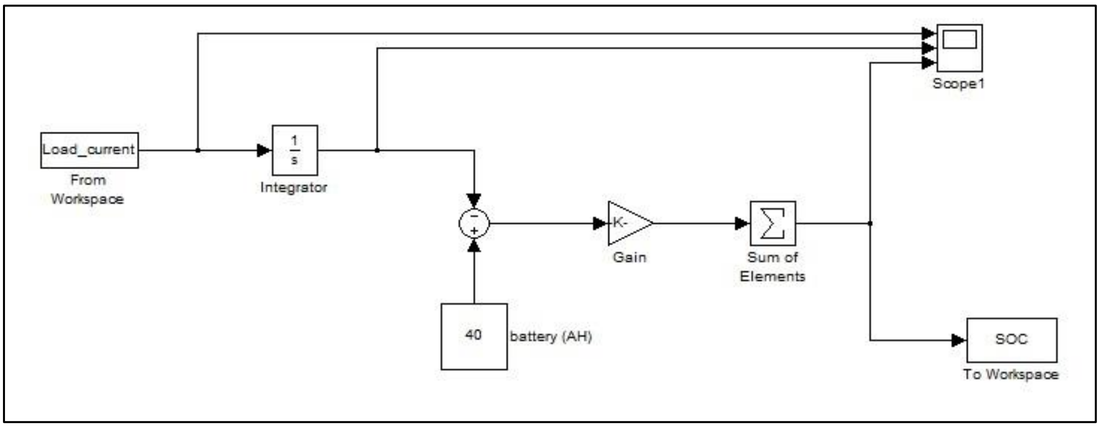


Fig.18: Coulomb counting simulation

For this simulation, the input taken from the current value that got from the experiment. The data imported through the excel document into the .mat file in the Simulink. After that, the current will integrate. The true value of the battery in unit AH will minus the integrate current, and then divide with the true value of the battery. The data will be sum up and shown the graph on the scope. The figure below showed the graph for this simulation.

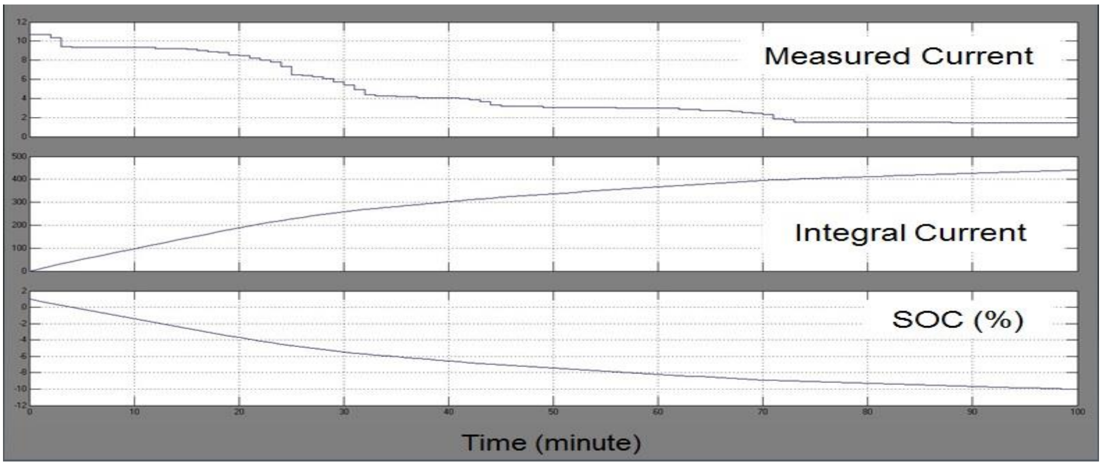


Fig.19: Coulomb counting simulation Graph

The graph showed exactly same as the experiment graph. This is because the calculation for both graph go under the same algorithm. The outcome of the graph is as expected.

4.3 Comparison

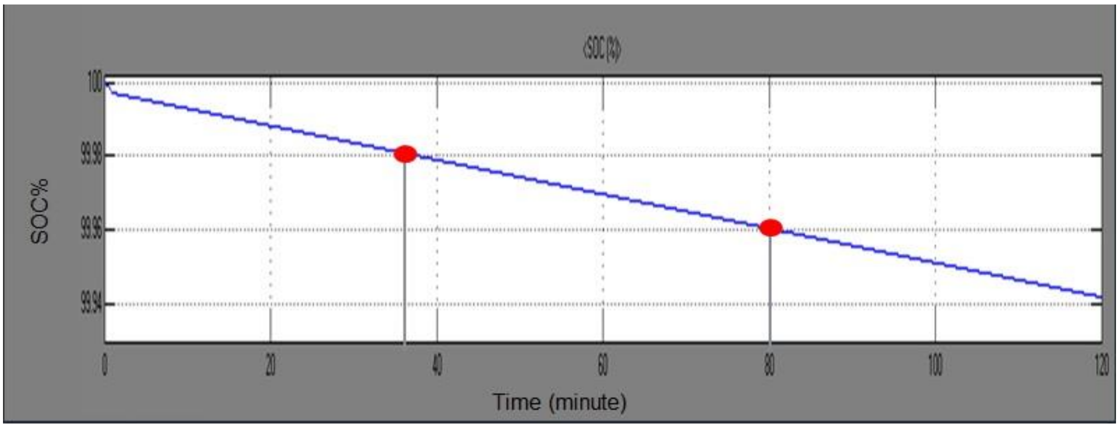


Fig.20: Simulation Graph

$C^2 = (99.98 - 99.96)^2 + (38 - 80)^2$

$C = \sqrt{1764}$

C = 42

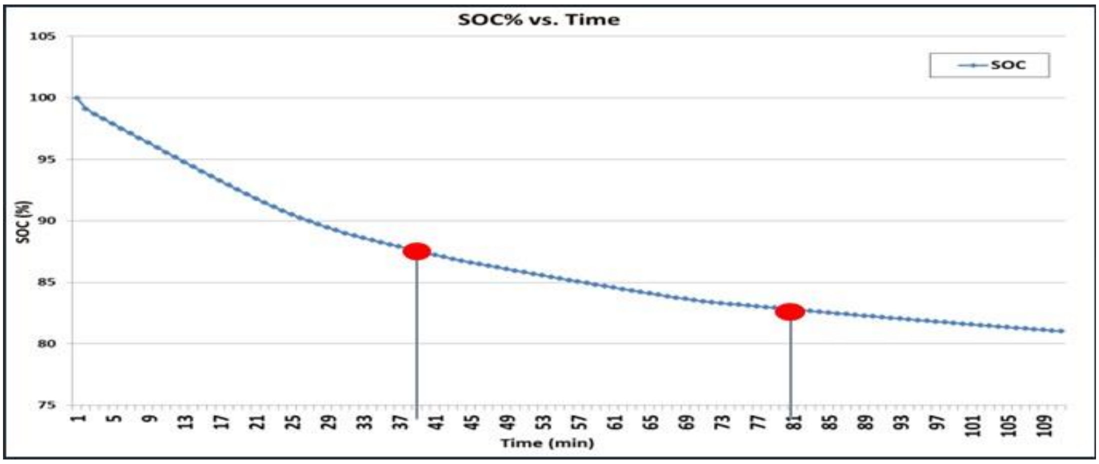


Fig.21: Experiment Graph

$C^2 = (88 - 83)^2 + (38 - 80)^2$

$C = \sqrt{1789}$

C = 42.3

Percentage Error Calculation:

$$\left|\frac{42 - 42.3}{42}\right| \text{x } 100\% = 0.71\%$$

Discharge characteristic for lead-acid battery between simulation and experiment have a little different. The gradient of the graph in the actual/simulation is higher than experiment graph. This might because of the human error or the materials or component that use in the experiment affect the result of the experiment. Other than that, the assumption that made in the simulation for the brushless DC motor is not same as the resistor that used in the discharged experiment. Therefore, there are slight different between two graph.

Chapter 5: Conclusion and Recommendation

As conclusion, this project is helpful in order monitor the battery of the hybrid vehicles. Besides that, it also can monitor the state-of-health (SOH) of battery. At some point, the method to monitor the battery already discovers which is by using the current clamp. The actual current found from the battery through the circuit will be inserting inside the formula to get the result of SOC. Other than that, the charging and discharging period on how long the cycle will take for the battery also been observe.

For the result, the methods that are being use are Coulomb counting. It is simple calculation with the integration of the current to find the SOC. For the period of discharging, it takes almost 2 hours to be completed. The simulation for the project already had been simulating in Simulink on the MATLAB. As for that, the result of simulation also has been compare with the result of the discharging experiment. Beside the simulation using the brushless DC motor, there are also simulations based on the Coulomb counting equation. By using the current data from the discharge experiment, the flow of calculation will show the same graph as the experiment's graph on the scope.

For the next step in this project, the overall circuit will built to conduct the charging experiment with Pspice software. If the circuit is completed built, it will be implemented inside the vehicle to observe the real result of the SOC for this continuous or on the road project. The real result will be compare with the result of the simulation of the battery. Furthermore, the circuit also need to be connecting to the Energy Management System (EMS) for further study.

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APPENDIX A

Table 5: Extract data from the experiment for 5 minutes

Time	Resistor (V)	Resistor (A)	Amp-Hour (AH)	Total Amp-Hour Discharged
15:55	9.7	10.66	0.17766	0.35531
16:00	8.5	9.34	0.15568	1.15202
16:05	8.5	9.34	0.15568	1.93041
16:10	8.3	9.12	0.15201	2.69414
16:15	8.1	8.90	0.14103	3.41026
16:20	5.9	6.48	0.10806	4.01100
16:25	4.9	5.38	0.08974	4.48353
16:30	3.8	4.18	0.06960	4.83884
16:35	3.7	4.07	0.06777	5.17583
16:40	2.9	3.19	0.05311	5.46155
16:45	2.8	3.08	0.05128	5.72162
16:50	2.8	3.08	0.05128	5.97620
16:55	2.7	2.97	0.04945	6.22346
17:00	2.5	2.75	0.04579	6.45606
17:05	2.1	2.31	0.03846	6.65203
17:10	1.4	1.54	0.02564	6.78390
17:15	1.4	1.54	0.02564	6.91210
17:20	1.4	1.54	0.02564	7.04031
17:25	1.3	1.43	0.02381	7.16119
17:30	1.3	1.43	0.02381	7.28023
17:35	1.2	1.32	0.02198	7.39562
17:40	1.2	1.32	0.02198	7.50551
17:45	1.2	1.32	0.02198	7.59342