Battery characterization of hybrid car

Wan Tarmizi Wan Isa, Sanisah Saharin, Wan Wardatul Amani Wan Salim

Abstract--- In this paper, batteries are characterized in order to propose a better monitoring and to maximize the energy outputs of the hybrid car. The characteristics of the batteries are compared between two types of the batteries, which is a lead-acid battery, and lithium-ion polymer battery. A simulation model by software COMSOL™ Multiphysics is conducted to simulate the characteristic of the electrochemistry of the batteries and to calculate the voltage drawn as well as the polarization in order to find the optimum characteristics for the hybrid car. For both batteries, the outcomes are voltage drops, state-of-charge (SOC), discharge rate, and the rate of capability. Simulation results indicate that lithium-ion polymer has a higher specific energy and specific density that hybrid car needed compared to the lead-acid battery.

Keywords: Hybrid Car; Lead-Acid Battery; Lithium-Ion Polymer.

1. INTRODUCTION

Nowadays, the global is introduced with the new technology that helps people to live an easy life. One technology that most used in worldwide is a battery. The battery is used almost everywhere on anything. The development of battery still in progress as it still can be integrated into more complicated technology. In the automotive field, the battery is already been introduced into the consumer market with such a model such as the Toyota Prius, Civic Insight, Chevy-Volt and many more (as shown in Table 1, [1]). Batteries for hybrid Electrical Vehicles are quite different from those used in consumer electronic devices such as laptops and cell phones. They are required to handle high power (up to a hundred kW) and high-energy capacity (up to tens of kWh) within a limited space and weight and at an affordable price [2].

However, the interest in battery technology development into more effective implementation is still in progress. The effective implementation would allow a significant portion for consumers to use their automobile without any faulty in battery or reduce the cost of maintenance. However, in order to develop a safe, effective and efficient battery technology, important research regarding the battery electrochemistry, charging and discharging characteristic, optimal state of charge (SOC) and performance need to be intensely investigated.

A cell is an electrochemical unit while a battery is made of two or more cells connected in parallel or series to create a certain operating rating. In the electrochemical process of the cell, the oxidation reaction occurs at the anode that is a positive electrode. This means that electron is released to the external circuit. In the meantime, the reduction reaction occurs at the negative electrode cathode.

The engine and electric motor in full hybrids (power assist HEVs) contribute to powering the car, with electric power being used for starting and acceleration. Currently the Li-ion battery is the only system being considered for powering PHEVs because of its high specific energy and energy density, although its properties are still considered insufficient [6].

Table 1: Batteries used in Electric Vehicles of Selected few Car Manufacturers [1].

Company	Country	Vehicle Model	Battery Technology
GM	USA	Chevy-Volt	Li-ion
Ford	USA	Escape, Fusion, MKZ HEV	NiMH
		Escape PHEV	Li-ion
Toyota	Japan	Prius, Lexus	NiMH
Honda	Japan	Civic, Insight	NiMH
Hyundai	South Korea	Sonata	Lithium Polymer
Chrysler	USA	Chrysler 200C EV	Li-ion
BMW	Germany	X6	NiMH
		Mini E (2012)	Li-ion
Daimler Benz	Germany	ML450, S400	NiMH
		Smart EV (2010)	Li-ion
Tesla	USA	Roadster (2009)	Li-ion
Think	Norway	Think EV	Li-ion, Sodium/Metal Chloride
Nissan	Japan	Leaf EV (2010)	Li-ion
		Altima	NiMH

2. MATERIALS AND METHODS

2.1 Lead-acid battery

Positive electrode: Lead dioxide (PbO_2)

This material is commonly used for the positive electrode as the ability of the metal for the oxidation reaction. It is of intermediate bond types that display both ionic bonds as it has a lattice structure and covalent bond as it has insolubility in water and low melting point properties [7]. Lead dioxide has a distinctive character to act as an electrode potential as it can be polarized both cathodically and anodically. In electrolysis, lead dioxide started to form on pure lead in the aqueous sulfuric acid when it is polarized at an anode.

Negative electrode: Pure lead (Pb).

Lead has a characteristic to dissolve in acid thus shows the high ability in electronegativity. When lead acid is

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dissolved in the acid such as sulfuric acid, it discharges into lead sulfide solid, hydrogen ion plus two electrons where the negative plate becomes anode since the material is being oxidized. During charge, the negative plate becomes cathode as it goes under the reduction process while the positive plate is being reduced to become anode [7].

Electrolyte: Sulfuric acid (H_2SO_4)

Sulfuric acid is in the water; it separated into two ions that are hydrogen and sulfate. Every each of sulfate ions contains two excess of electrons and therefore it carries two negative electric charges. While for each hydrogen ion, it has been stripped down into one electron and it carries one positive electric charge. Sulfuric acid is very highly reactive, it ionizes almost completely and so there will very few fully assembled molecules of sulfuric acid in the electrolyte at any instant [8]. The ions are in continual motion as it is attracted and repelled by one another by the water and any impurities in the mixture.

2.2 Lithium-ion polymer

Positive electrode: Lithiate cobalt oxide ($LiCoO_2$)

The cells that are using Lithiate cobalt oxide ($LiCoO_2$) have a higher energy density and a better life cycle which is approximation around 500 to 700 with deep discharge cycles. The main problem with this material is that it releases a large amount of energy when abused and thus it will result in a fire.

Lithiate nickel, cobalt and aluminium oxides (NCA) is said to have a slightly lower voltage at full charge and a larger margin to accept overcharge become the new choice of battery manufacturer. NCA has superior life characteristics in cycling and therefore become the new best option as a positive material for many automotive industries for their hybrid electric vehicles. Meanwhile, Lithiate nickel, manganese and cobalt oxides (NMC) has a better cycle life than $LiCoO_2$ although the presence of manganese oxide makes NMC subjected to increased capacity fading compared to NCA. If safety on overcharge aspect is ranked, NMC ranks at the top between NCA and $LiMn_2O_4$ [9].

Negative electrode: Graphite.

Graphite is the most viable selection in lithium-ion cells. This is because of the significant feature of graphite that has so low (so negative) to react instantly with the electrolyte [9]. Graphite is commonly used as the active material in negative electrodes mainly because it can reversibly place Lithium-ions between its many layers. This reversible electrochemical capability is maintained over several of thousands of cycles in batteries with optimized electrodes.

Electrolyte: Polyacrylonitrile-based (PAN).

PAN was introduced for the electrolyte host matrix material as it has small thermal resistance and flame-retardant properties. PAN-based has ionic conductivity between 10^{-5} S cm^{-1} to 10^{-3} S cm^{-1}. The negative effect of using PAN-based gel polymer electrolyte is that the internal resistance of the lithium-ion polymer becomes higher.

Polymethyl methacrylate-based (PMMA). This electrolyte enhanced interface stability and low cost. This is because its rich raw materials and simple synthesize process among other host matrix materials but it has a poor mechanical flexibility. Thus, it narrows down the applications of this electrolyte. Polyvinylidene fluoride-based (PVdF). It is the most commonly used polymer in lithium-ion polymer nowadays. It contains a strong electron- withdraw function groups (-C-F) to induce a net dipole moment. The PVdF-based also has a high dielectric constant that supports a high concentration of charge carriers [9-14].

3. MODELLING AND SIMULATION

A simulation is conducted by using COMSOL™ Multiphysics under Battery and Fuel Cell Module. The simulation is using time-dependent with initialization study in the model builder. The result obtained and calculated by using software time-dependent solver. Table 2 lists the comparison between the lead-acid battery and lithium-ion polymer battery. Meanwhile, Table 3 shows the selection of materials for the batteries for simulation purpose.

Table 2: Typical properties of lead-acid and lithium-ion polymer batteries [4].

	VRLA Lead-Acid	Lithium-Ion Polymer
Energy Density (Wh/L)	100	250
Specific Energy (Wh/kg)	40	150
Regular Maintenance	No	No
Typical State of Charge Window	50 %	80 %
Voltage Increments	2 V	3.7 V

Table 3: Materials selection of the batteries for simulation.

	Lead-Acid	Lithium-Ion Polymer
Positive Electrode	Lead, Pb	NMC, Li Ni1/3Mn1/3Co1/3O2
Negative Electrode	Lead Oxide, PbO_2	Graphite, LixC6MCMB
Electrolyte	Sulfuric Acid, H_2SO_4	LiPF6 in 1:2 EC: DMC and p (VdF-HFP)

4. RESULTS AND DISCUSSION

For 0.5 C lithium-ion polymer (as shown in Fig. 1), it shows lower rate discharge until zero depth-of-discharge which is zero percent. In the same case but different cell that is the lead-acid battery; it shows a much higher rate of discharge compared to the 0.5 C lithium-ion polymer. This means that the 0.5 C lithium-ion polymer can sustain longer rate at the discharging. It is essential for an automotive manufacturer to consider this battery in designing a hybrid car for a longer ride journey. While for the higher rate rating which is 10 C each battery show the higher rate of discharge but yet the lithium-ion polymer shows the best result compared to the lead-acid battery in the same condition of rating. This is because of LiPF6 in 1:2 EC: DMC and p (VdF- HFP) have a higher capacity in containing ions to

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allow ions flow for a longer time from negative to positive electrode until zero percent depth-of-charge. This is due to the hybrid polymer electrolyte (HPE), where hybrid means the combination of the liquid solvent, the salt, and the polymer matrix. This result obtained from voltage versus depth-of-discharge is disregarding the heat loss and performance drop during discharge and considering it has a perfect heat flow in and out for both batteries at the ambient temperature which is 298 K (25°C).

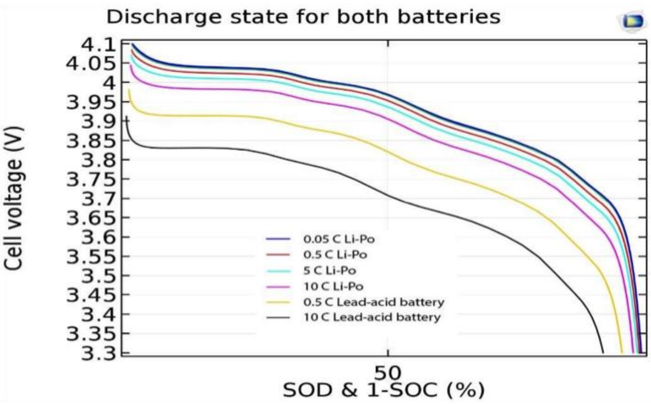

Fig. 1: Discharge state for both lead-acid and lithium-ion polymer batteries.

As in Fig. 2, the charge result voltage versus state-of-charge obtained shows that for both batteries, they have the same pattern but only differ in value. For 0.5 C lithium-ion polymer, it shows the lowest rate of charge compared to the others. It shows that this lithium-ion polymer takes a longer time to get a full charge. It is due to the polymer matrix containing in the electrolyte of the lithium-ion polymer. For 10 C lead-acid battery, it has a higher rate of charging compared to the others. This is due to the 10 C rating of lead-acid battery has a higher rate for a deep cycle charge. The sulfuric acid is in an aqueous state that allows the fastest movement of ion either in discharging and charging.

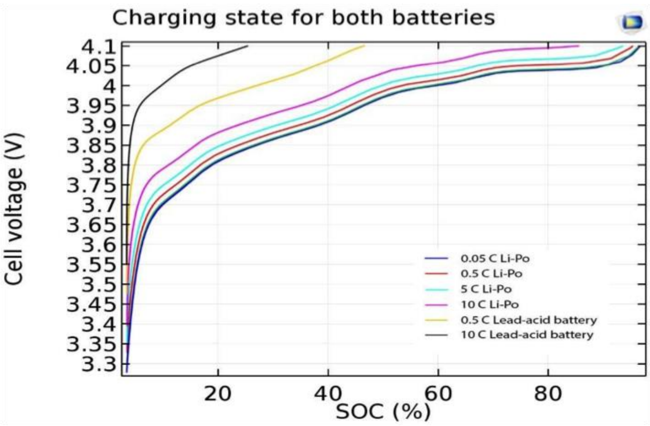

Fig. 2: Charging state for both lead-acid and lithium-ion polymer batteries.

While 10 C lead-acid battery has the highest rate of charge, but the 10 C lithium-ion polymer can be considered to be the best option of selection for a hybrid car. This is because in charging state, the gradient between each battery at the same rating is small in inclination while it has a large gradient in declination between 10 C and 0.5 C from both types of batteries. If compared with both result in Fig. 1 and Fig. 2, the lithium-ion polymer has a higher capability for optimizing for a hybrid car.

Fig. 3 shows the behaviour when the batteries are operated in pulse mode. In the simulation, the load drew a pulsed current for one period that sets for 20 seconds. The 0.5 C lithium-ion polymer shows the higher state of fidelity compared to the others. It is because of the less exertion from the slow discharge and a higher density of the cell gives a good feedback to the operation mode compared to the same rating of 0.5 C lead-acid battery. For the 10 C rating, the lead-acid battery exerts a high pulse and before rise up during load is on. But due to a higher rate of a deep cycle, lead-acid battery rise up rapidly to reach a higher point after half period compared to the lithium-ion polymer at the same rating.

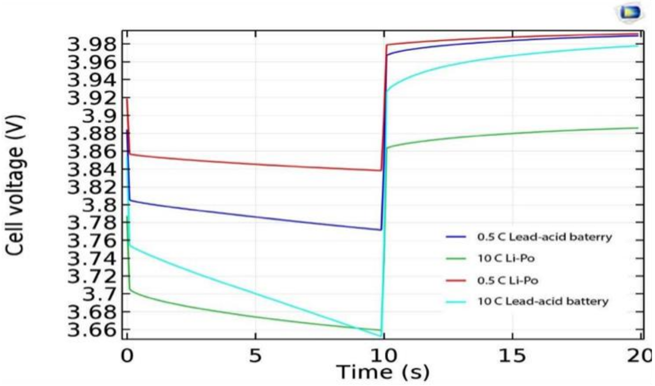

Fig. 3: Cell voltage during the hybrid pulse operation.

In Fig. 4, the graph shows the polarization for each battery. For the 10 C lead- acid battery, it shows the highest voltage drop. This is because the battery exerted a higher pulse during a period. In addition, the higher rate deep cycle gives one of the reasons for the voltage drop. The 0.5 C lithium-ion polymer shows the lowest in polarization during a hybrid pulse. This is due to the less exertion during a hybrid pulse and high-density cell of lithium-ion polymer battery.

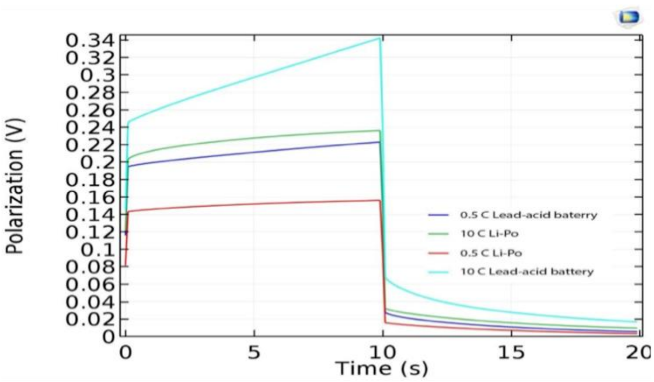

Fig. 4: Polarization behavior during the hybrid pulse operation.

Fig. 5 shows a Ragone plot for both lead-acid and lithium-ion polymer batteries at various rating. The lithium-

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ion polymer has a reliable data to solid the proof that it is the best option for optimizing battery for the hybrid car. Regardless rating of the battery, the lithium-ion polymer has a higher specific energy and specific density that hybrid car needed compared than the lead-acid battery.

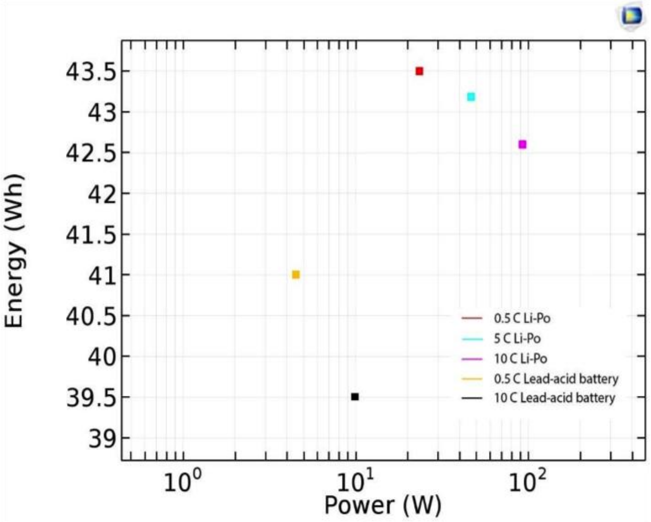

Fig. 5: Ragone Plot at various rating.

5. CONCLUSION

The lithium-ion polymer improved the battery characterization by increasing the value of the specific density of the battery. The lithium-ion polymer is well optimized for hybrid car manufacturer for those aiming for longer range miles and power. The voltage of lithium-ion polymer battery during the transient response of hybrid source is at the optimum range with the low voltage drop (polarization) compared to the lead-acid battery.

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