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State of Health Estimation in Lithium Polymer Battery

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Abstract. BMS is a system to manage the use of the battery and protect it from a condition that led to the failure performance of the battery. One of the components of BMS is State of Health (SOH), which refers to decreased performance of the battery. Estimation methods of SOH are required to reduce the possibility of failure of the battery. This research, systematically designed along through stages of battery test which consisted of the static capacity test, pulse test, and aging cycle test. The results of the testing stages were used to estimate the SOH. Two methods were used to estimate SOH i.e. Coulomb counting and open circuit voltage method. The decreasing of battery SOH could be seen from the changing in the maximum capacity as the number of cycles of the charging-discharging test was performed. The result of SOH estimation indicates that the coulomb counting method was better than the open-circuit voltage method, with the smaller of mean absolute error, mean square error, and mean absolute percent error.

INTRODUCTION

The use of fossil-fueled cars today was continuously growing, as well as the demand of fossil-fueled cars. Growth in the number of cars also has an impact on the use of fossil fuels which can lead to global warming. Then, the electric car was created and developed. Electric cars use batteries as the energy source. Despite It still relatively less popular than fossil fuel cars because of relatively more high price and problem regarding battery charging, it can overcome the problems of global warming due to the environmentally friendly use of the batteries, free emissions, and noise machines. The user of electric cars is predicted to increase rapidly to triple by 2020 [1].

Batteries as the energy storage device are the key which determined the failure or success of the operation of the electric car. To avoid battery failure that can lead to the failure of all systems on the car, it needs a battery management system (BMS) that can regulate the use of the battery efficiently and safely as possible. BMS controls the use of the battery in the healthy battery area and provide information to the operator to perform the necessary actions, such as stopping the use of the battery or charging the battery, so battery condition remains good.

One of the information provided BMS is a State of Health (SOH). SOH reflect the general state of the battery and its ability to provide the specified performance compared to the new conditions. SOH enables prediction of the end of battery life and avoids unexpected interruption of the system that can cause damage or hazardous events. In an electric car, SOH indicator informs the user that the maintenance or battery replacement is needed when it reaches a certain degradation threshold so it could reduce the possibility of failure of the battery.

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THE STATE OF CHARGE, STATE OF HEALTH, AND BATTERY MODEL

State of Charge and State of Health

State of Charge (SOC) is defined as the ratio of the remaining capacity of the battery and the total capacity of full charge when the battery is performed under the same conditions. SOC is often expressed in percent, 100% means full capacity and 0% means an empty capacity [2]. Precise SOC estimation can avoid unpredictable system disturbances and prevent the battery from overcharge and over discharge, which can cause permanent damage to the internal structure of the battery [3]. Coulomb counting method (CC) and open circuit voltage (OCV) is widely used to estimate the SOC. CC method is the simplest and most common method to get the battery SOC [2]. This method can be expressed as follows,

$$SOC = SOC_0 - \frac{1}{C_N}\int_{t_0}^{t} \eta I \cdot d\tau \tag{1}$$

where SOC_0 represents SOC at the initial time t_0; C_N represents rated capacity (the capacity of the battery in standard condition, changing with service life); η represents coulombic efficiency which is equal to 1 while discharging and is smaller than 1 while charging; I represents current which is negative at charge and positive at discharge. Open circuit voltage after the battery reaches sufficient rest can be considered to reach steady voltage, since there is a correspondence between the OCV and the SOC and support the little relationship of battery life, this is an effective method for estimating the SOC of the battery [2].

Battery usage and natural aging can change the battery performance. That's because changing the State of Health (SOH) of the battery; the SOH can be assimilated to a "measurement" that reflects the general condition of the battery and its ability to provide the specified performance compared to the new conditions. This is why the estimated SOH is one of the most important issues in the application of the battery [4]. SOH is not associated with a specific physical quantity, and thus, there is no consensus in the world of scientists or industry on the precise definition of the SOH (or how it should be defined) [4].

Regarding capacity, the SOH can be defined by

$$SOH = \frac{Q_{max}(Aged)}{Q_{max}(New)}, \tag{2}$$

where Q_{max} is the maximum capacity that can be absorbed from the battery [5]. SOC value also refers to the value of the capacity of the equation (2) can be transformed into

$$SOH = \frac{SOC_{max}(Aged)}{SOC_{max}(New)}. \tag{3}$$

Battery Model

In this study, we used the battery model of Rint model. Rint models were shown in **Fig. 1**. The model of battery depends on a resistance R, the capacitor C, the capacitor voltage V_C and resistor voltage V_R [6].The relations of terminal voltage V_t with the capacitor voltage V_C can be represented by their respective Laplace as follows

$$\frac{V_c}{V_t} = \frac{1}{1 + sRC} \tag{4}$$

Equation (4) is returned to the time domain to

$$\frac{dV_C}{dt} \approx \frac{V_C[k] - V_C[k-1]}{T_s} \tag{5}$$

where T_s is the sampling time, then the equation (4) can be transformed into

$$V_C[k] = V_C[k-1] \cdot (1-\alpha) + V_t[k] \cdot \alpha \tag{6}$$

$$\alpha = \frac{T_s}{T_s + RC}.$$

Estimation of capacitor voltage indicates OCV battery. This means that the algorithm can be used to estimate the OCV.

BATTERY TESTING SYSTEM AND SCHEDULE

System Design

BMS was used to regulate the use of the battery, the block diagram shown in **Fig. 2**. The battery usage setting was done by controlling the switch to connect or disconnect the battery to the load and the charger so it can be charging or discharging or open circuit automatically as desired. Arduino UNO32 as a control for the switch, but it is also used to read current and voltage sensor data which are stored on the PC through the software MATLAB.

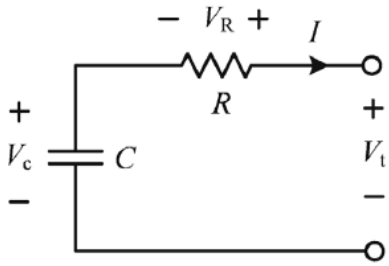

FIGURE 1. Rint battery model

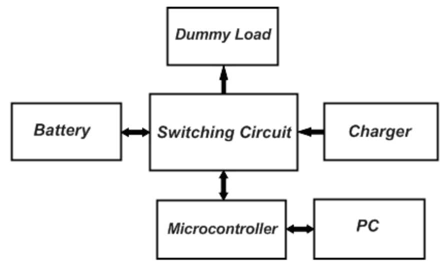

FIGURE 2. Experimental schematic design

Battery Test Steps

Static capacity tests and pulse test

The static capacity test aims to measure the capacity in ampere-hours (Ah) at constant current discharge rate, for example, the battery capacity is 2,2Ah, the discharge rate 2.2A. The discharge will end on voltage limits described in the battery products. If no voltage limit indicated on the product, then 50% of the maximum charge voltage of the battery used as a voltage limit. 1C discharge used as a reference for static capacity and energy measurement.

In the Static Capacity Test, charge the battery fully, then rest. Terminal voltage is measured as the OCV value at 100% SOC. Then constant current 1C discharge for one hour to obtain the value of the terminal voltage that is used as the discharge voltage limit. Battery rested, then the terminal voltage is measured as the OCV value at 0% SOC. Also, the difference between the terminal voltage and OCV can be used to determine the value of R.

Pulse Test is a test battery with input in the form of current pulses aims to get a graph OCV-SOC battery. OCV values obtained from the testing of each interval of 10% SOC with discharging 10% of the battery capacity. Every 10% discharging, the battery rested, applied to get OCV [6].

In this study, used the current value of 1C (2.2A) and then performed discharging of the battery for 6 minutes and rested for 12 minutes is repeated until the terminal voltage reaches the limit discharge voltage. Furthermore, to better show the characteristics of the battery, then testing to receive graphics OCV-SOC by way of discharge of 30 seconds and 30 seconds of rest repeated until it reaches a predetermined voltage. Graph OCV-SOC obtained from the test results are used to determine the value of the voltage OCV at 80% SOC and 20% SOC.

Aging cycle test

At each aging cycle, charging or discharging the battery with constant current mode until it reaches the specified voltage [7]. Cycle life is determined by the number of cycles of charge-discharge a battery in which the battery can work well before its nominal capacity falls below 80% of the initial capacity of the battery. A large number of cycles needed to show the effects of the degradation of the battery.

In this study, Aging Cycle Test performed by 30 cycles of charge-discharge. Aging Cycle Test done in the range of 80% SOC to 20% SOC as an area work battery. From the experimental results, the maximum SOC changes in each cycle were observed for the analysis of changes in battery SOH.

SOH Estimation Method

There are two methods to estimate the SOH, coulomb counting (CC method) and open circuit voltage (OCV method) respectively. To get the value of SOH, both methods require the value of SOC. CC method acquires SOC changes from the value of current multiplied by time. OCV method uses V_C value from (6) as the OCV value to get the value of SOC from SOC-OCV graph. Each SOH estimation is obtained by using a calculation method from (3).

Figure 3. is a flowchart SOH estimation algorithms. Flowchart shows the sequence estimation method SOH with CC and OCV method. Also, the flowchart is also showing the flow of determining the SOH based on the actual data is called into SOH experiments. SOC value in SOH experiment obtained by using the measured OCV value when the battery is being rested after a charge for each cycle. OCV value is inserted into the SOC-OCV function.

RESULTS AND ANALISYS

Static Capacity Test and Pulse Test

From the static capacity test obtained OCV at 100% SOC, limit full discharge voltage, and OCV at 0% SOC is 4.234V, 3.528V, and 3.661V. To obtain the value of R, the difference between OCV (4.234V) and terminal voltage (4.114V) instantly connected load divided by the current, in this study the current value of 2.2A to obtain the value of resistance is 0.054 Ohm.

In pulse test, the interval between discharge and short rest will show battery discharge characteristics similar to the results of the testing of the static capacity test. Fig. 4 show the SOC-OCV graph, so the graph is used to estimate the SOC on the battery model used in this study. In addition to voltage OCV, the current value of 80% SOC and 20% SOC is 4.17V and 3.643V.

From the graph in **Fig. 4**, obtained equation of SOC (OCV) which can be expressed as follows

$$SOC(x) = k_1x^9 + k_2x^8 + k_3x^7 + k_4x^6 + k_5x^5 + k_6x^4 + k_7x^3 + k_8x^2 + k_9x + k_{10} \tag{7}$$

where k_1=47953.512, k_2=-1715648.223, k_3=27271125.136, k_4=-252780321.599, k_5=1505724856.404, k_6=47953.512, k_7=15813055635.6, k_8=-26883598844.646, k_9=26651373368.144, k_{10}=-11738484461.365, x=OCV. The equation used in the battery model for determining the initial value of SOC at the CC method and for determining V_t in the right model to obtain the value of V_c that can be used to get SOC value at the OCV method.

Aging Cycle Test

Voltage graphs aging cycle test are shown in **Fig. 5** for 6 cycles of a total of 30 cycles of charge-discharge. When the positive current value, the battery is discharging. When the current value is negative, the battery is charging. When the current value is zero, the battery in an open circuit (rest).

The graph shows that the charging voltage value is noisy compared to discharging. When charging, if the average value of the data of last 30 charging voltage is greater than the limit voltage, then the battery will be disconnected from the charger. A total of 30 cycles of charge-discharge from the aging cycle test was used to look for changes in battery SOC based on the data of voltage and current for each method.

State of Health Estimation

Terminal voltage value immediately before discharging used to determine the value of SOC based on the equation (7) is regarded as the value of SOC experiment to get SOH experiments. **Fig. 6** shows a graph of the maximum SOC changes to both methods and the SOC experiment. The graph shows that the decreased battery capacity indicated by SOC changes as the number of cycles. In the first cycle, the maximum SOC value for the CC method, OCV method, and SOC experiment was 78.192%, 80.318%, and 79.005%. At the 30th cycle, the maximum SOC value for CC method, OCV method, and SOC experiment was 75.746%, 80.033%, and 77.932%. Results of changes in the maximum SOC is used to estimate the value of SOH. Initials maximum capacity of the battery is proportional to the maximum SOH value at the beginning of the cycle. When the next cycle there is a maximum SOC value that is greater than the initial value, the maximum SOC value becomes the new initial value. SOH obtained by the calculation equation (3).

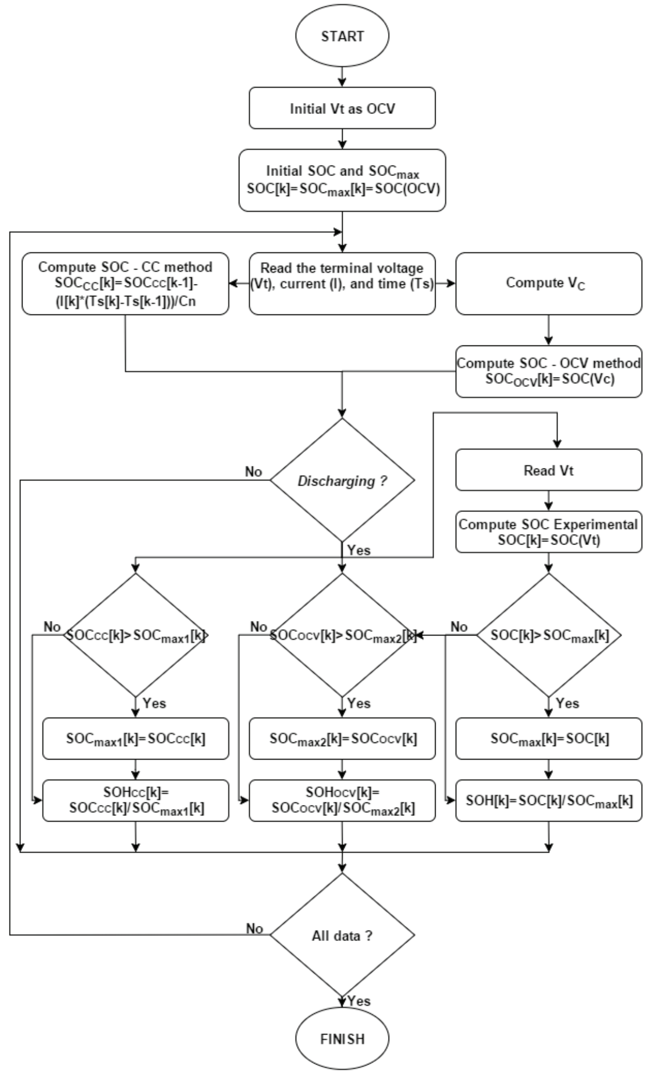

FIGURE 3. SOH estimation flowchart

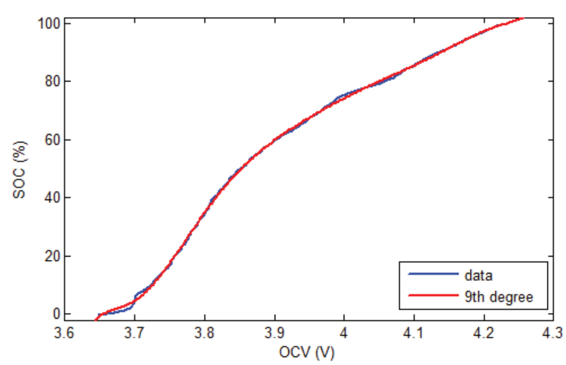

FIGURE 4. SOC-OCV plot

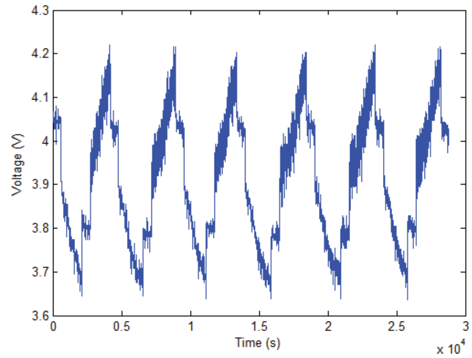

FIGURE 5. Vt in six cycles plot

Figure 7. shows a graph of the change SOH for both models and experiments. The graph shows that the battery SOH has decreased as the number of cycles. At the 30th cycle, the value of SOH to CC method, CV method, and the experiment was 96.581%, 99.233%, and 97.839%. The results of both methods were compared with SOH experiments and obtained the errors for both methods. Errors in all cycles used to find the mean absolute error, mean square error, and mean absolute percent error in both models are shown in **Table 1**. From **Table 1**, the first method has the mean absolute error, mean square error, and mean absolute percent the smallest error.

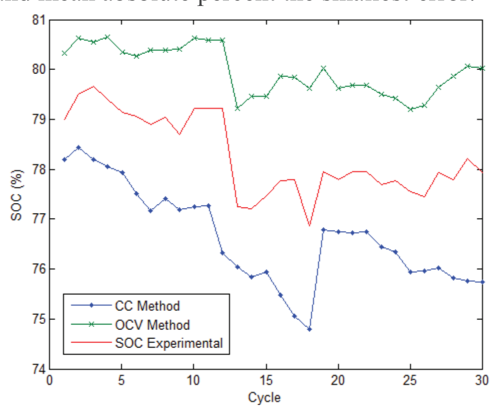

FIGURE 6. SOCmax plot

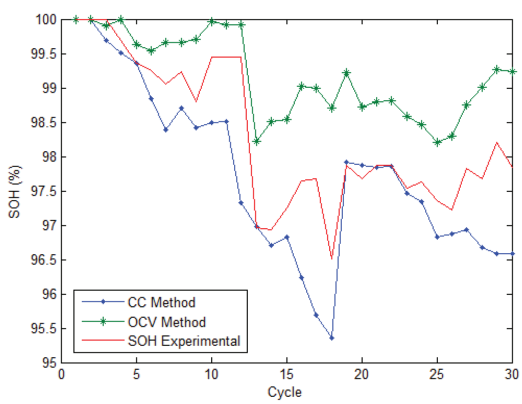

FIGURE 7. SOH plot

TABLE 1. Error of SOH estimation

Method	Mean Absolute Error	Mean Square Error	Mean Absolute Percent Error
Method CC	0,5990	0,7146	0,6098 %
Method OCV	0,8715	1,0198	0,8915 %

CONCLUSION

Based on the obtained result, the conclusions that can be drawn are as follows:

1. We have successfully estimated the State of Health (SOH) of the battery.
2. The SOH of the battery will decrease with changes in the maximum capacity as the number of cycles of charging-discharging.
3. The CC estimation method is more accurate than the method OCV.
   In the next work, changes in the internal resistance should be considered along with shifts in the maximum capacity to estimate the State of Health (SOH) of the battery.

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REFERENCES

1. G. Dinger, Andreas; Martin, Ripley; Mosquet, Xavier; Rabl, Maximilian; Rizoulis, Dimitrios; Russo, Massimo, Sticher. "Focus Batteries for Electric Cars," (2010).
2. L. Lu, X. Han, J. Li, J. Hua, and M. Ouyang, J. Power Sources **226**, 272–288 (2013).
3. K. S. Ng, C. S. Moo, Y. P. Chen, and Y. C. Hsieh, Appl. Energy **86**, 1506–1511 (2009).
4. S. Santhanagopalan, J. Stockel, and R. E. White. J. B. T.-E. of E. P. S. Garche. Encyclopedia of Electrochemical Power Sources, 418–437 (2009).
5. M. Shahriari and M. Farrokhi," State of health estimation of VRLA batteries using fuzzy logic," in *2010 18th Iranian Conference on Electrical Engineering (ICEE)* (IEEE, 2010), pp. 629–634.
6. C. Y. Chun, J. Baek, G.-S. Seo, B. H. Cho, J. Kim, I. K. Chang, and S. Lee, J. Power Sources **273**, 255–263 (2015).
7. X. Hu, S. Li, and H. Peng, J. Power Sources **198**. 359–367 (2012).