State of Charge, State of Health, and State of Function Monitoring for EV BMS[1]

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Abstract – **The computation and monitoring of three key indices, namely, state of charge (SOC), state of health (SOH), and state of function (SOF) for EV (electrical vehicle) BMS (battery management system) are proposed in this work. Because most of SOC definitions are directly related to nominal capacity, the accuracy of residual capacity is doubtful. Therefore, the SOC is redefined by present maximum capacity to reduce the error of the SOC estimation. The measurement of the proposed SOC demonstrates that the maximum error is 0.334 %. Moreover, this paper also proposes SOF based on SOC and SOH to reveal the driving power of the system.**

I. INTRODUCTION

Recently, the electric vehicle (EV) has become the most popular green transportation selection. EV has many advantages, including eco-friendly, energy saving, economy and comfortness, as compared to the conventional gas vehicles. Certainly, EV has been evolved into a product of many mainstream automobile makers.

Fig. 1 shows a typical power system in an EV [1], where BMS plays a key role in the power system. BMS is mainly composed of many battery modules, various sensors and electronic control units (ECU). A battery module is made of many battery strings to generate a high voltage and generate large currents. Therefore, BMS is designed to monitor or estimate battery conditions, including voltage, current, remaining-range predictions, health condition, and power capability estimation. Notably, state of charge (SOC), state of health (SOH), and state of function (SOF) are the basic parameters to evaluate the whole BMS.

SOC of the battery can be clearly defined as the residual capacity in the battery with respect to the nominal capacity. Many methods were proposed to calibrate the SOC. Kim *et al.* proposed a modularized charge equalizer to estimate SOC, which is based on the open circuit voltage (OCV) battery model [2]. SOH is defined as the present maximum capacity, which is affected by cycles of charge and discharge. Even if the variation of the SOH is slower than SOC, SOH is still considered as the important indicator to determine the battery availability. Finally, SOF is defined as the ability of the battery can execute a specified function (e.g., engine starting) or not.

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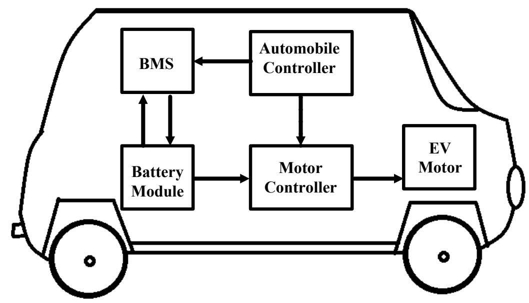

Fig. 1. The Power system in an EV

II. ARCHITECTURE OF BATTERY MODULE SYSTEM

Fig. 2 shows the proposed BMS in this work, including high voltage (HV) current sensor [3], two analog-to-digital converters (ADC), a Battery state monitor, and a communication port. The voltage of the battery module is monitored by ADC1. The HV current sensor is used to monitor the current of the battery module. The Battery state monitor estimates SOC, SOH, and SOF based on the acquired voltage and current data of the battery module. Finally, communication port converts the battery state into an RS232 format to be displayed on the user's screen.

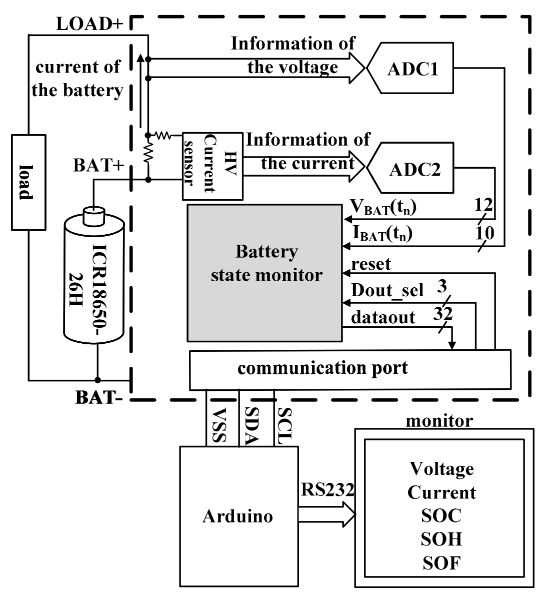

Fig. 2. The proposed block diagram of the BMS

This paper re-defines SOC as the residual capacity in the battery with respect to the present maximum of the battery, as shown in Eqn. (1).

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$$\mathrm{SOC}(t)=\frac{Q(t)_{\text{residual capacity}}}{Q_{\text{present maximum capacity}}} \tag{1}$$

where $Q(t)_{\text{residual capacity}}$ is the residual capacity of the battery, $Q_{\text{present maximum capacity}}$ is the present maximum capacity of the battery. $Q(t)_{\text{residual capacity}}$ is measured by OCV and coulomb integral as Eqn. (2).

$$Q(t_n)_{\text{residual capacity}}=Q(t_0)_{\text{residual capacity}}-\int_0^{t_n} i(t)dt \tag{2}$$

Then, $Q_{\text{present maximum capacity}}$ can be written as Eqn. (3).

$$Q_{\text{present maximum capacity}} = Q_{\text{nominal capacity}} \times \mathrm{SOH} \tag{3}$$

According to the charge/discharge cycle of the battery specification (ICR18650-26H) [4] and our experimental data, a lookup table is developed for SOH.

SOF is a digital signal stating whether the battery has sufficient power capability to reach a pre-defined task. The output of the SOF based on the SOC, SOH, and, e.g., forecast distance is described in Eqn. (4) – (6).

$$\begin{aligned}&\text{Remaining Powertrain}\\&\qquad= \text{SOC} \times \text{nominal capacity} \times \text{SOH}\end{aligned} \tag{4}$$

$$\begin{aligned}&\text{Consuming Powertrain}\\&\quad= \text{Average Power consumption} \times \text{forecast distance}\end{aligned} \tag{5}$$

$$\text{SOF}=\begin{cases}1, \text{if Remaining Powertrain}\\ \qquad\qquad \geq \text{Consuming Powertrain}\\ 0, \text{if Remaining Powertrain}\\ \qquad\qquad < \text{Consuming Powertrain}\end{cases} \tag{6}$$

III. IMPLEMENTATION AND MEASUREMENT RESULTS

An experimental prototype is carried out by the proposed BMS and automatic battery cycler (WBCS3000) as shown in Fig. 3.

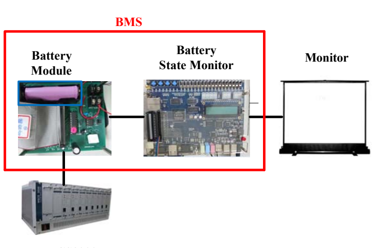


Fig. 3. Measurement setup of the proposed BMS.

The measurement results of the SOC are shown in Fig. 4. Fig. 5 shows error of the SOC. Additional, The maximum error with respect to measurement results of the WBCS3000 is as low as 0.334 %. Fig. 6 shows that the proposed SOF successfully determines whether the battery has sufficient power capability to arrive the destination. The proposed BMS and several prior works are tabulated in Table I, where our design demonstrates the least error of SOC and the functionality of SOF.

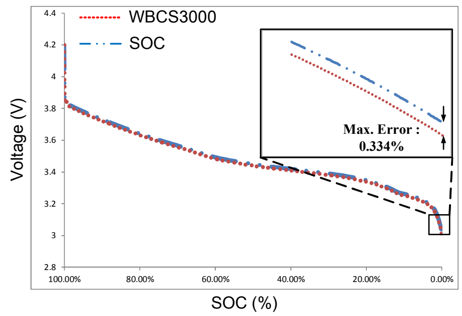


Fig. 4. The measurement results of SOC.

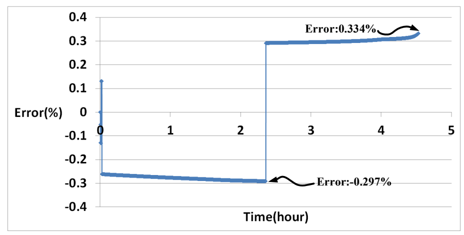
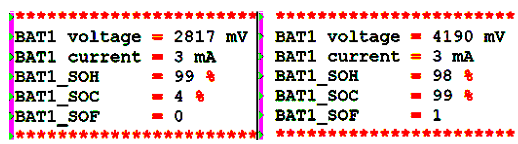


Fig. 5. Error of SOC (with respect to WBCS3000 outcome)



(a) (b)

Fig. 6. The decision of SOF (a) can't arrive (b) can arrive

TABLE I
PERFORMANCE COMPARISON OF BMS

	[5]	[6]	[7]	This work
Year	2015	2015	2015	2016
Technology	MATLAB	FPGA	online	FPGA
SOC error (%)	9.62	0.07	0.7	0.334
SOF function	N/A	N/A	N/A	Yes

REFERENCES

[1] http://itri.org.tw

[2] J. Kim, G.-S. Seo, C. Chun, B.-H. Cho, and S. Lee, "OCV hysteresis effect-based SOC estimation in extended kalman filter algorithm for a LiFePO4/C cell," in *Proc. IEEE International Electric Vehicle Conference*, pp. 1-5, Mar. 2012.

[3] C.-C. Wang, W.-J. Lu, and S.-S. Wang, "An on-chip high-voltage current sensor for battery module monitoring," in *Proc. 2014 IEEE International Conference on IC Design & Technology (ICICDT)*, pp. 1-4, May 2014.

[4] *ICR18650-26H Datasheet*, Samsung, Suwon, Korea, 2009.

[5] C.-C. Wang, S.-S. Wang, M.-Y. Tseng, and W.-J. Lu, "A capacity monitoring system with HV current sensor and calibrated current estimation approach," in *Proc. IEEE Region 10 Conference (TENCON),* pp. 1-4, Nov. 2015.

[6] T. Kim, W. Qiao, and L. Qu, "Hysteresis modeling for model-based condition monitoring of lithium-ion batteries," in *Proc. IEEE Energy Conversion Congress and Exposition (ECCE)*, pp. 1-6, Sep. 2015.

[7] G.-W. You, S. Park, and S. Lee, "Data-driven SOH prediction for EV batteries," in *Proc. 2015 IEEE International Conference on Consumer Electronics (ICCE)*, pp. 577-578, Jan. 2015.