리튬이온 배터리의 과전압/저전압을 막기 위한 회기 최소 자승법 기반의 실시간 내부 저항 추정방법

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Online Identification of Li-ion Battery's Internal Resistance based on a Recursive Least Squares Method to Prevent Overvoltage/Undervoltage

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ABSTRACT

This paper proposes an on-line estimation algorithm of internal resistance of Li-ion battery based on the recursive least squares method to prevent the overvoltage and undervoltage casing degradation of life cycle of battery. An equivalent circuit model with single time constant is adopted, and under assumptions that the terminal voltage, current and SOC are measured accurately, the discrete time based nonlinear equation of the model can be converted to the linear equation which can be applied to recursive least squares method. Since the coefficients of the discrete time linear equation can be expressed by the parameters of the equivalent circuit model, it is shown that an internal resistance (R_i) can be estimated in real time using the least square method.

1. Introduction

Electrified vehicles are promising solutions to the problems resulted from traditional internal combustion engine vehicles for examples, the oils crises and specially the environmental issues. Among the many components that make up an electrified vehicle, the performance of the electrified vehicle greatly depends on a battery system. Therefore, the Li-ion batteries are widely used for electrified vehicle because the Li-ion battery has advanced characteristics compared to the conventional batteries such as high power density, low self-discharge rate and long cycle life. Although the Li-ion batteries have these advanced characteristics, if it does not operate in the normal operating area, it is easily damaged, and even worth, because of the high potential, the Li-ion batteries can explode or ignite if the batteries operate under the harsh condition [1]. Hence, it is important for the BMS to eliminate the fear of overvoltage and undervoltage causing negative effect to the batteries during motoring and regenerating operation [2].

In this paper, to prevent overvoltage and undervoltage, the online IR estimating algorithm is proposed. The two kinds of available currents; chargeable current and dischargeable current can be estimated from the estimated internal resistance (IR), terminal voltage and limited voltages. The terminal voltage can be measured however, the IR should be estimated by certain algorithm. Hence, to estimate the available current, with some assumptions, the IR is identified based on a recursive least squares method (RLSM).

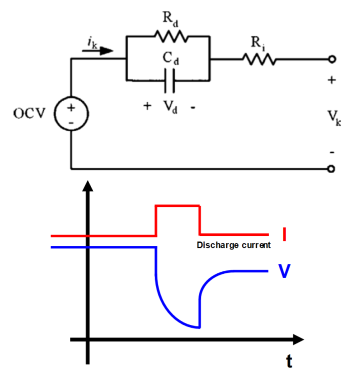

Fig. 1. Equivalent circuit model and resulting voltage with engaged current

2. Proposed IR identifying algorithm

2.1 Li-ion battery model

In this paper, a battery's equivalent circuit model (ECM) containing a series resistor Ri and single RC circuit is used. Fig. 1 shows the battery model and terminal voltage response when the constant pulse current is engaged [3]. When the current is engaged, the voltage drop or rise occurs because of two kinds of ohmic voltage changes and decreasing or increasing potential of battery (SOC change).

During vehicle operation, the IR consistently changes with respect to not only the SOC but also the aging (see the Fig. 2). Therefore, the parameter values which are estimated offline and coded in BMS software can be different from the real parameter values. The amount of parameter difference become larger over time. It causes the unexpected voltage drop or rise getting the terminal voltage out of undervoltage or overvoltage limits. To prevent the undervoltage and overvoltage, the maximum current should be estimated online by identifying the IR.

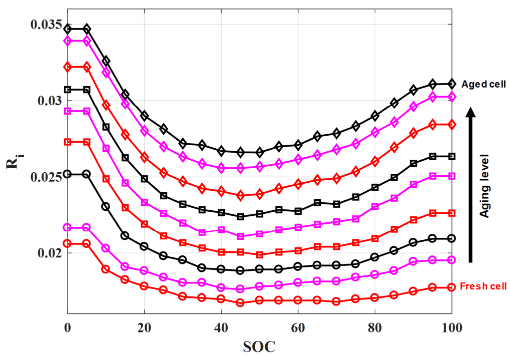

Fig. 2. Tendency of Internal resistance change with respect to the SOC and aging level

2.2 Identifying the IR based on the RLSM

A dynamic equation on discrete time domain of the ECM in Fig. 1 is derived as follows:

$$z(k+1)=z(k)-\frac{\Delta T}{Q}I(k) \quad (1)$$

$$V_d(k+1)=\left(1-\frac{\Delta T}{R_dC_d}\right)V_d(k)+\frac{\Delta T}{C_d}I(k) \quad (2)$$

$$V_t(k)=V_{OC}(z(k))-V_d-R_iI(k) \quad (3)$$

where the V_{OC} is nonlinear function representing relationship between SOC which is represented by *z* and OCV. To use the RLSM, it is necessary to convert the above equations to linear model *y=βX*, where *β* is a vector of unknown parameters. Let define the new variable *y(k)* as follow.

$$y(k)\triangleq V_t(k)-V_{OC}(k) \quad (4)$$

From Eq. (1) to Eq. (4), the new linear dynamic equation of *y(k)* and *I(k)* can be derived as follow.

$$y(k)+\left(\frac{\Delta T}{R_dC_d}-1\right)y(k-1)= -R_iI(k)+\frac{-(R_i+R_d)\Delta T+R_iR_dC_d}{R_dC_d}I(k-1) \quad (5)$$

$$y(k)=\begin{bmatrix}a_0 & a_1 & a_2\end{bmatrix}\begin{pmatrix}y(k-1)\\ I(k)\\ I(k-1)\end{pmatrix}, where\ a_0=1+\frac{\Delta T}{R_dC_d}, \quad a_1=-R_i, a_2=\frac{-(R_i+R_d)\Delta T+R_iR_dC_d}{R_dC_d} \quad (6)$$

Although, Eq. (6) is represented by linear model, there are unknown values V_{OC}, V_t and I. Therefore, it is necessary to assume that the terminal voltage and current can be measured correctly by sensors, and the V_{OC} can be estimated correctly by external SOC estimator. From Eq. (6), the RLSM can estimate the unknown parameters *a0*, *a1* and *a2* based on Eq. (7). Especially, the IR can be directly identified because the Ri equals to the –a1.

$$\begin{cases} V_{(N+1)}=\dfrac{1}{\mu}\left(V_{(N)}-\dfrac{V_{(N)}x_{N+1}^Tx_{N+1}V_{(N)}}{1+x_{N+1}V_{(N)}x_{N+1}^T}\right)\\ \gamma_{(N+1)}=V_{(N+1)}x_{N+1}^T\\ e=y_{N+1}-x_{N+1}\hat{\beta}_{(N)}\\ \hat{\beta}_{(N+1)}=\hat{\beta}_{(N)}+\gamma_{(N+1)}e \end{cases} \quad (7)$$

2.3 Estimation of a maximum current based on R_i and voltage limits

According to the datasheet of target battery cell SAMSUNG INR 18650−25R, the maximum charge cut−off voltage is limited to 4.2 V and the minimum discharge cut−off voltage is limited to 2.5 V. To prevent overvoltage and undervoltage, the maximum dischargeable and chargeable current should be bounded based on the IR and voltage boundary. From the IR estimator proposed at the last section, the maximum currents can be obtained as follows:

$$I_{\max.char}=\frac{V_{t.\max}-V_{t.measured}}{\hat{R}_i} \quad (8)$$

$$I_{\max.dischar}=\frac{V_{t.measured}-V_{t.\min}}{\hat{R}_i} \quad (9)$$

where the $I_{max\ char}$ and $I_{max.dischar}$ is the maximum chargeable current and maximum dischargeable current and *Ri_hat* is the estimated IR from IR estimator. The motor should not generate or drive more than the maximum currents.

2.4 Experimental results

The two kinds of cells are experimented. One cell is fresh cell which has 2.52Ah discharging capacity and the other one is aged cell which has 2.24Ah (89% of fresh cell) discharging capacity. It is easy to be expected that the aged cell has a higher IR. The IR estimating results are shown in Fig. 3. The true IR can be measured based on the hybrid pulse power characterization (HPPC) current−voltage curve.

3. Conclusion

In this paper, the on−line IR identification algorithm based on the RLSM is proposed. Although this algorithm needs an assumption that the SOC is estimated accurately by external estimator, the output of this IR estimator can be used to calculate the maximum current which prevents the overvoltage and undervoltage causing negative effect to the battery.

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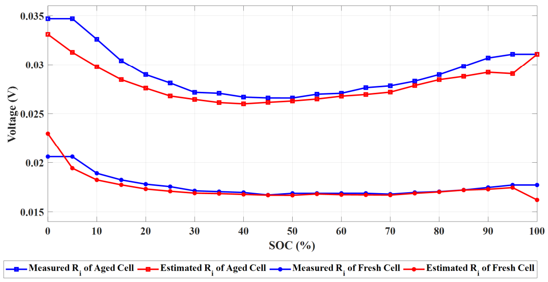

Fig. 3. The IR estimating results; squared−line represents to the aged cell and circled−line represents to the fresh cell

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