SOC Estimation of Power Battery Design on Constant-current Discharge

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**Abstract:** This paper takes the electric car’s power battery (VRLA battery cell) as the research object, for real-time monitoring problem of power battery's state of charge (SOC) and remaining time, The system adopts micro control unit (MCU) 89S51 and AD974 to control battery discharge in constant current, Through the measurement of a periodic, get Series of working voltage, using phase-slope calculation method at this time calculating the battery's SOC and remaining time. Through the experiment, this estimation method proved the feasibility of the dynamic working point can be mapped to the static working point, and the largest relative error is no more than 7%. For further improving the measurement accuracy and reducing error, Through the software can realize appropriate correction and compensation of temperature, aging and other interference factors. Error analysis results show that this method has small error, high measurement accuracy. Copyright © 2014 IFSA Publishing, S. L.

**Keywords:** Constant-current discharge, Real-time voltage, SOC estimation, Power battery.

1. Introduction

The state of charge for power battery usually will be affected by environmental temperature, discharge ratio, charging time, aging degree and other factors. At present, the electric cars and other battery users, before use or in working condition, know the actual battery remnant capacity is very important. Inaccurate measurement of battery’s SOC will have a direct effect on charging, because can't accurately predict whether “shallow discharge” or “over discharge”, make the battery “over charge” or “under charge”, resulting in shortened battery life, increase cost. By this token, accurate measurement of SOC has become the bottleneck for it’s widely replace fuel energy [1]. The SOC test is complex, commonly used methods are: density estimation, Ampere-hour counting estimation, open-circuit voltage estimation, internal resistance or impedance estimation method, etc. In recent years, people also developed the Kalman filter recursive estimation algorithm, fuzzy logic method and neural network method.

2. Measurement Method of SOC

The estimation method of SOC should be different with the working environment, namely according to the working environment and put forward the corresponding strategies [2].

2.1. Ampere-hour Estimation

Ampere-hour method estimate battery SOC in charging and discharging process through
calculating energy accumulation, and according to the temperature, discharge rate for SOC compensation [3]. The method is simple and adopted by most electric cars on the market at present. Because of the battery charging efficiency empirical estimates, and the same cut-off discharge voltage value is usually in reference each time, i.e. cell voltage of 1.75 V for the SOC zero, but each different work voltage leads to discharge to the cell voltage of 1.75 V is not necessarily the corresponding SOC zero, so the error accumulation.

2.2. Impedance Estimation

The existence problem of impedance measurement is battery impedance numerical small, numerical small variation range also; therefore, the impedance’s small changes can’t use to describe the whole SOC [4]. Some studies have found, while cycle times are not the same, the measured impedance may be the same, but the SOC is different [5].

2.3. Kalman Filter Recursive Estimation

The important role of Kalman filter is the system state estimation. When the interference is the normal distribution, it gives minimum variance estimation. Otherwise, the linear minimum variance state estimation is given [6]. It uses repeated recursive operation "estimating - correction ", in order to achieve the best results at each moment. However, Kalman filtering algorithm must be set up on the mathematical model, computational complexity, at the same time, the choice of initial value is also very important, error initial value will lead to recursive error intensifies.

2.4. Neural Network Estimation

Neural network can fully approximation arbitrary complicated nonlinear model. To the power battery, its internal mathematical model was unknown and the neural network may be the most suitable method to complete its capacity state estimation [7]. The method of neural network must be train on the base of the traditional method for the accumulation of experience. Therefore, we must first ensure the accuracy of the empirical data, to ensure the accuracy of the estimated neural network.

3. Constant-current Discharge Research

To find more simple and convenient method for on-line measurement of SOC, constant current discharge of battery were research firstly.

3.1. Experimental Mode and Conditions

The battery model is 6-DZM-10, nominal voltage is 12 V. The experimental temperature is 25 ± 2 °C. The discharge model is constant current discharge, discharge rate is 0.24 C2, discharge termination voltage is 10.5 V (Cell voltage is 1.75 V).

3.2. Constant Current Discharge Curve

Constant current discharge curve as shown in Fig. 1. It is divided into two parts [8]: the first part is the platform voltage part, should account for 80 % ~ 90 % of the discharge curves and presents linearly; the second part declines sharply, in the final stage of curve. The battery is low voltage in second stage, and rapid decay to the termination voltage, therefore, should try to avoid the battery in the area.

![Fig. 1. Constant current discharge voltage-time curve.](image)

Battery discharge capacity is relevant with work mode. When the discharge range fixed, the temperature is the same, do not consider aging factors, in the same termination voltage, discharge power is not the same. According to the agreed working mode discharge 6 times get discharge voltage curve is shown in Fig. 1. Although the initial discharge voltage is different, the slope of the discharge curve is basically the same. The horizontal axis change corresponds to a working voltage of U (t) to the discharge terminate time is t; Fig. 1 is transformed into the Fig. 2. In Fig. 2, the remaining time corresponds to an operating voltage, the voltage of 12.10 V and 11.50 V as example in Table 1. Because the discharge is the constant current, the remaining time can be expressed for SOC (current × time).

By analyzing the relationship between the power battery constant current discharging voltage and the remaining time, the following conclusions can be obtained: the battery voltage under constant load, to determine the power battery in real-time condition SOC. Because the load of the battery in the working
state is uncertain, in special circumstances, to decrease the output current may occur accident, therefore, setting a preset load for the battery, in order to complete the detection of voltage at any time under a constant load.

The equivalent circuit of the battery is shown in Fig. 3 [9]. $R_{i}$ is ohmic resistance which including the electrode and electrolyte and conductor resistance etc. $R_{d}$ is diffusion resistance and polarization resistance. $C_{\text{surface}}$ is double layer capacitance. $R_{d}$ is self-discharge equivalent resistance. The open circuit voltage is equivalent capacitance $C_{\text{bulk}}$. Bhangu has given voltage mutation in the relationship between the dynamic process and parameters as shown in Fig. 4 shows [10]. Give $R_{i} = 0.0026 \, \Omega$, $C_{\text{surface}} = 23 \, \text{pF}$, get time constant $\tau = 0.059 \, \text{s}$, the adjustment time of dynamic process $t_{s} = 0.1794 \, \text{s}$. In Shinya Sato test, the voltage and current range from 4.8 A to 2.4 A, 11.99 V to 12.09 V in 1s, verified the dynamic switch to static possibility. At the same time, method can use parallel large capacitor to solve the problem of load transient power loss.

### 3.2. Discuss the Dynamic Transition Time

Because the battery voltage and output current is inversely proportional, load of power battery changes with time, and the nature of the load uncertainty, therefore, the voltage value must appear fluctuated beating phenomenon, the transition time is uncertain. In order to make the detection of the working voltage have a true reflection of SOC real-time status, and give certain control to transient time, battery external a pure resistance constant current load, and cycle discharge battery with constant current, measuring the working voltage. Based on the above analysis, the voltage will drop in the curve of constant current discharge which can determine the current remaining time and SOC.

The test voltage and corresponding to the remaining time are shown in Table 1.

<table>
<thead>
<tr>
<th>Test Voltage (V)</th>
<th>1 t/min</th>
<th>2 t/min</th>
<th>3 t/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.10</td>
<td>147.90</td>
<td>144.78</td>
<td>146.10</td>
</tr>
<tr>
<td>11.50</td>
<td>55.75</td>
<td>54.12</td>
<td>53.11</td>
</tr>
<tr>
<td>Test Voltage (V)</td>
<td>4 t/min</td>
<td>5 t/min</td>
<td>6 t/min</td>
</tr>
<tr>
<td>12.10</td>
<td>167.22</td>
<td>143.36</td>
<td>142.87</td>
</tr>
<tr>
<td>11.50</td>
<td>56.33</td>
<td>52.69</td>
<td>58.16</td>
</tr>
</tbody>
</table>

### 4. Working Voltage Convert to SOC

In test, the input voltage of 10.5 ~ 13 V divided to 7 segments. In actual application, the battery according to accuracy requirements can be divided into more small. Considering the discharge voltage curve fall very rapidly in later stage, increased the later voltage range, the discharge voltage platform area was subdivided into 13 ~ 12.70 ~ 12.40 ~ 12.10 ~ 11.80 ~ 11.50 ~ 11.25 ~ 10.50 V. Similarly, the remainder time area of the corresponding is also divided into 7 sections. As shown in Table 2.

According to the specific situation of each section calculate the discharge curve slope is shown in Fig. 5, and obtained the slope formula 1. In formula, $u_{ci}$ corresponding to the starting voltage of segment $i$, $u_{zi}$ corresponding to the ending voltage of segment $i$, $t_{ci}$ is the start time of segment $i$, $t_{zi}$ is the end time of segment $i$, $K_{i}$ is the slope of the segment $i$. 

![Fig. 2. Constant current discharge voltage and discharge termination time curve.](image)

![Fig. 3. Battery equivalent circuit diagram.](image)

![Fig. 4. The dynamic process of cell voltage mutation.](image)
### Table 2. Operating voltage and the remaining time segments and the slopes

<table>
<thead>
<tr>
<th>Slope/Ki</th>
<th>Operating voltage/V</th>
<th>Remaining time/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0148</td>
<td>13.00–12.70</td>
<td>300–280</td>
</tr>
<tr>
<td>0.0047</td>
<td>12.70–12.40</td>
<td>280–210</td>
</tr>
<tr>
<td>0.0051</td>
<td>12.40–12.10</td>
<td>210–150</td>
</tr>
<tr>
<td>0.0058</td>
<td>12.10–11.80</td>
<td>150–95</td>
</tr>
<tr>
<td>0.0073</td>
<td>11.80–11.50</td>
<td>95–53</td>
</tr>
<tr>
<td>0.0130</td>
<td>11.50–11.25</td>
<td>53–26</td>
</tr>
<tr>
<td>0.0286</td>
<td>11.25–10.50</td>
<td>26–0</td>
</tr>
</tbody>
</table>

Fig. 5. The piecewise slope for remaining time.

\[
K_i = \frac{u_{ci} - u_{cj}}{t_{ci} - t_{cj}} \quad (1)
\]

By judging the working voltage measurement belongs to the section, the measured working voltage \( u_i \) corresponding remaining time \( T_i \) as:

\[
T_i = t_{ci} - \frac{u_{ci} - u_i}{K_i} \quad (2)
\]

For example: measured a working voltage of \( u \) is 11.35 V, the remaining time is \( T \):

\[
T_i = 53 - \frac{11.5 - 11.35}{0.013} = 41.46 \text{ min}
\]

### 5. Measurement and Error Analysis

The system adopts MCU 89s51 and AD974 to control battery discharge in constant current, cycle test battery’s operating voltage under constant load, use the slope measurement method to calculate the battery SOC. The sampling period set to 1 min, estimate the working voltage of the remaining time. Due to the actual discharge voltage in the first stage there is a "steep drop and rise" and is not stable, therefore, the initial battery SOC use its open circuit voltage to estimate.

Absolute error checking is shown in Fig. 6. Among them, \( T_s \) is measured remaining time of Ampere-hour counting estimation method, \( T_j \) is the time remaining use the piecewise meter slope method calculated in this paper.

Fig. 6. Absolute error checking.

\[
e_{se} = \frac{T_j - T_s}{T_s} \times 100 \% \quad (3)
\]

Fig. 7 shows the relative errors of \( e_{se} \) use following formula calculate:

Fig. 7. Relative error checking.

### 6. Conclusions

Through analysis the voltage characteristic curve of the VRLA battery in constant current discharge mode, the working voltage under constant load can be used to determine the power battery’s SOC in real-time condition. For battery discharge current uncertain characteristic, put forward a new technique using dynamic voltage measurement battery SOC.
This method through the external constant current load, measured periodically a series of dynamic operating voltage of the battery, and the dynamic operating voltage map to the pre-set fixed ratio discharge voltage curve, according to preliminary get voltage curve slope, calculate the real-time condition SOC. Error analysis results show that, this method overcomes the shortage of SOC estimation using multivariable control method, has the characteristics of small error, high precision, simple and practical, suitable for different temperature, different aging degree of the battery, to better meet the user on-line dynamic measurement the SOC requirements.

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References


