Detection method of battery working status for electric vehicle based on real-time vehicle condition

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Abstract. With the popularization of electric vehicles, the maintenance of power batteries has gradually become a major research topic in the maintenance of electric vehicles. This paper proposes a battery aging detection method based on the real-time vehicle condition of electric vehicles. Through the monitoring of current changes, the change of ohmic internal resistance of power battery is observed. And through the SOC changing trend when the electric vehicle is running, the battery health status is estimated, thereby effectively providing a reference for the user's electric vehicle maintenance. According to changes in the SOC, SOH, and ohmic resistance of the power battery, it is determined whether the power battery needs to be replaced.

1. Introduction
With the incomplete charging station layout today, users face difficulty in driving EV (Electric Vehicle) for a long-distance travel [1]. Secondly, the time consumed during the charging process makes many car owners reluctant to drive EV. Even a fast DC charge takes 1 to 2 hours to charge a common car while increasing battery pressure [2]. The third point is battery loss. Batteries charging and discharging back and forth will influence battery performance, resulting in the necessity of replacing the battery [3].

Quite a few studies have realized the accurate estimation of SOC (State of Charge) on the basis of the Kalman filter and big data. The Kalman filter can correct the metering value [4], we can accurately estimate the SOC value of the power battery at any time [5].

SOH (State of Health) is also an important index to judge the long-term performance of power battery. At present, the research mainly focuses on how to estimate the SOH value of power battery based on big data through support vector machine (SVM) and Bayesian algorithm [6]. In this paper, the method is proposed to estimate the change of SOC during normal driving of electric vehicle, and the aging degree of electric vehicle is characterized from the aspect of battery.

2. SOC and SOH of power battery

2.1. SOC
SOC is defined as the ratio of the amount of electricity currently remaining after the battery is used to the total amount of the battery charged under the same conditions that can be produced:
SOC = \frac{Q_r - Q_d}{Q_r} \times 100\% \quad (1)

\( Q_r \) is the total amount of electricity that can be released when the battery is discharged at a constant current from the beginning of full charge, and \( Q_d \) is the amount of electricity already released by the battery over a period of time.

The ordinary amperometric method regards the charge stored in the battery as a linear system, and the SOC value of the battery can be roughly estimated by integrating the discharge current to the time. The formula is as follows:

\[ S_t = S_{t_0} + \frac{1}{Q_r} \int_{t_0}^{t} \eta \cdot i_t \cdot dt \quad (2) \]

\( S_t \) and \( S_{t_0} \) are the SOC values of the battery at the time \( t \) and time \( t_0 \), \( \eta \) is the discharge efficiency and \( i_t \) is the instantaneous discharge current value. The influence of the aging degree of power battery, the temperature of use and the discharge rate should be considered. Therefore, it is necessary to correct formula (2).

\[ S_t = S_{t_0} + \frac{1}{Q_r} \int_{t_0}^{t} k_i \cdot k_T \cdot i_t \cdot dt \quad (3) \]

\( k_i \) is the discharge current correction coefficient and \( k_T \) is the temperature correction coefficient. The parameters can be determined by previous experiments. The accuracy can be controlled to less than 5% combined with various filtering algorithms.

2.2. SOH

SOH is defined as the ratio of the total amount of electricity actually released when the battery is fully charged against the nominal quantity when it leaves the factory.

\[ SOH = \frac{Q_r}{Q_N} \quad (4) \]

\( Q_r \) is the total quantity of energy that can be actually released when the battery is fully charged, and \( Q_N \) is the nominal total quantity. It is generally believed that batteries cannot be used as power batteries and need to be recycled when \( SOH < 0.8 \).

3. Monitoring model for ohmic internal resistance

3.1. PNGV model

At present, the commonly used models are: the simple structural RINT model proposed by Idaho National Laboratory, the SAFT capacitance model proposed by SAFT Battery Company of France, and the PNGV model which is introduced and used in this paper.
The full name of PNGV is Partnership for a New Generation of Vehicles, also known as the New Generation of Vehicles. PNGV is the standard battery model proposed in its manual and has been used consistently so far. Its circuit diagram is shown in Figure 1.

According to the PNGV battery model, the equation of state space can be written.

$$
\begin{pmatrix}
U_1 \\
U_2 \\
\end{pmatrix} = \begin{pmatrix}
0 & 0 \\
0 & -\frac{1}{R_S C_2} \\
\end{pmatrix} \begin{pmatrix}
U_1 \\
U_2 \\
\end{pmatrix} + \begin{pmatrix}
\frac{1}{C_1} \\
\frac{1}{C_2} \\
\end{pmatrix} I_t \\
V_t = (-1) \begin{pmatrix}
U_1 \\
U_2 \\
\end{pmatrix} - R_t I_t + E_t \\
$$

(5)

3.2. Ohmic internal resistance
According to the PNGV model, select the ohmic internal resistance of the battery as the state variable:

$$
R_t (t + \Delta t) = R_t (t) + r (t) \\
V_t (t) = F(S(t)) - \int R_t (t) - U_2 (t) + g (t) \\
$$

(6)

It is called the state space model of power battery. Among them, the state variable, that is, the variable ohmic internal resistance, and the noise of the state variable and the observational quantity, respectively; and the electromotive force which can be generated when the SOC value of the battery is the value. If the coefficient of the system observation equation is:

$$
e_{ij}^{R_t} = \frac{dU_t}{dR_t} |_{R_t = R_t (t)} = -I_t \\
$$

(7)

In fact, the parameter estimation and the state estimation are carried out by double filters respectively. The state space model of the power battery is brought into the above model, and the ohmic resistance value can be estimated by the loop iteration of the computer and simultaneously estimating the system state and the model parameters.

4. SOH calculation method based on real-time vehicle condition

4.1. Power battery monitoring system
The monitoring system of the power battery pack is shown in Figure 2. The current, voltage, temperature and other data of the battery pack are collected by the sampling module, and converted into a digital signal uploading micro control unit (MCU) to realize functions such as control and storage. At the same time, the processed data will be connected to the vehicle control unit (VCU) and the electronic control unit (ECU) through CAN communication to partially control the electric vehicle.

4.2. Real-time SOH calculation
The estimation of the battery SOH based on real-time vehicle conditions is based on an accurate estimate of the SOC.

When the electric vehicle runs normally, every other time period $\Delta t$, the real-time SOC value of the power battery is calculated by formula (3). When the SOC changes to a certain extent $\delta$:

$$
S_t - S_{t0} \geq \delta \\
$$

(8)

the electric quantity output during the period in which the SOC value changes, that is, the amount of change in the battery power during the period of time, is calculated by the above formula in the formula (9):
\[
\begin{cases}
\Delta Q = \sum_{i=1}^{i_d} V_i I_i \Delta t \\
\Delta Q_N = \sum_{i=1}^{i_d} V_{N,i} I_{N,i} \Delta t
\end{cases}
\]  

(9)

\(i_d\) is the number of time periods \(\Delta t\) in which the SOC value changes, \(\Delta Q_N\), \(V_{N,i}\) and \(I_{N,i}\) are the amount of electricity, voltage and current that should be discharged under the same conditions of the nominal battery. \(V_{N,i}\) and \(I_{N,i}\) are respectively a piecewise linear function.

\[
NQV = \sum_{i=1}^{i_d} V_{N,i} I_{N,i} \Delta t
\]

After finding \(\Delta Q\) and \(\Delta Q_N\), the theoretical SOC can be obtained with the following equation:

\[
SOH = \frac{\Delta Q}{\Delta Q_N}
\]

(10)

It can be seen that the formula (10) is the same as the formula of SOH in formula (4). It is also necessary to consider the terrain of the electric vehicle when driving or the special situation of traffic:
\[
SOH = \frac{\sum_{j=1}^{n} \Delta Q_j}{n \Delta Q_N}
\]  

(11)

Among them, \(\Delta Q_j\) represents the output power of the battery in each period of time during \(n\) periods; \(n\varepsilon\) is the total SOC changes during this period, \(\Delta Q_N\) is the amount of power that can be released when the new battery produces the same change in SOC. Equation (11) reduces the impact of sudden changes in vehicle conditions. In addition, special cases need to be removed if the following formula is satisfied:

\[
\frac{\Delta Q_j - \Delta Q_{j-1}}{i_g - \Delta t} > \varepsilon \{Q_{j-1}\}
\]

(12)

The output flow chart of real-time SOH calculation is shown in Figure 3.

5. Case analysis

5.1. SOC

A comparison of the battery SOC estimation curve and the actual SOC curve obtained by using the corrected ampere metering method is shown on (a) of Figure 4. True value is calculated by \(\Delta Q/\Delta t\).

![SOC and resistance estimation result comparison chart](image)

Figure 4. SOC and resistance estimation result comparison chart.

In addition to the noise and rounding errors in data acquisition, the temperature measured during actual experiments is delayed. Therefore, when the stored electricity is low, the estimated value of the SOC produces a certain deviation. The overall error can still be controlled at 7.30%.

5.2. Ohmic Internal Resistance.

The increase in ohmic internal resistance reflects the degree of aging of the power battery. Also, in the case of pulse discharge, the comparison of the ohmic internal resistance change curve and the actual internal resistance change curve estimated by the system state model is shown on (b) of Figure 4. True value is measured by electrical impedance meter.

The estimation error obtained by the simulation result is 6.05%, which can accurately estimate the change of the ohmic internal resistance of the battery. The change includes both a permanent increase caused by battery charge and discharge, and a temporary change caused by operating temperature and SOC.

5.3. SOH

The selection period \(\Delta t\) is 50s, \(n\) equals 10, and the battery SOH is calculated for every 500 seconds. The estimated SOH curve is compared with the actual SOC curve as shown on (a) of Figure 5. When
the selection period is 50s, n equals 6, and the battery SOH value is calculated for every 300 seconds. The estimated SOH curve is shown on (b) of Figure 5. True value is calculated by equation (4).

It can be seen from the figure that the estimate of SOH is actually quite accurate within 6000 seconds of the discharge of the battery. The relative errors of the tests in the two figures are 8.37% and 7.68%, respectively. It can be used as a battery fitness criterion for the vehicle while driving.

![Figure 5. Battery SOH estimation results comparison chart.](image)

6. Summary
This paper achieves the following results through real-time state detection methods based on real-time vehicle conditions including SOC, SOH and ohmic internal resistance of EV batteries:

(1) A real-time SOH estimation method based on real-time SOC value is proposed, and its practical application value is verified by simulation experiments, which can provide EV owners with numerical reflection of real-time battery aging degree.

(2) Through the summary of real-time SOC, ohmic internal resistance and SOH estimation method under real-time vehicle condition. The relative error of SOC, resistance and SOH are about 7.30%, 6.05% and 7.68%.

(3) A set of system solutions including MCU and VCU is developed for the common monitoring system of power battery SOC, SOH and ohm internal resistance, which meets the needs of actual use.

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