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Design of On-line Measurement Module of Internal Resistance for Lithium-ion Battery

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Abstract. Internal resistance of battery reflects its characteristics, including State of health, inconsistency, state of charge, charge and discharge ability, thermal runaway. On-line measurement of internal resistance can monitor the running state of each battery in real-time and accurately, can diagnose fault state of battery and handle fault in time. This paper implements the practical system of on-line measurement of internal resistance for lithium-ion battery using AC analysis. Experimental result shows that the system is simple, stable, reliable, and low cost.

Keywords:lithium-ion battery; On-line measurement of internal resistance; AC analysis

Introduction

As the power source and the carrier of energy of electric vehicles, battery plays a very important role in electric vehicle. Only in terms of cost, the price of battery is accounted for 1/2 of the EV's total price [1]. The battery can be equivalent to a voltage source with internal resistance, and also can be equivalent to a two-port device. In addition to voltage and current, internal resistance is the important electrical parameter of the battery which indicates performance of the battery. Internal resistance really reflects the state of health [2, 3], state of charge, and also can accurately monitor thermal runaway of the battery [4, 5]. Internal resistance detection increases the accuracy of the diagnosis of the inconsistencies of battery.

Module design

On-line measurement system of internal resistance is composed of three parts: On-line measurement module of internal resistance, USB-CAN, host software. On-line measurement module of internal resistance can complete internal resistance measurement, internal resistance data coding, CAN data transmission and other functions. Because the computer have no CAN interface, the communication between On-line measurement module of internal resistance and host is realized based on USB-CAN. Host software can record, analyze and store the internal resistance data in real-time.

Principle of On-line Measurement Module of Internal Resistance. The internal resistance of the battery includes the ohmic internal resistance and the polarized internal resistance. Fig. 1 shows the simplified practical model of internal resistance of batteries, where Ro stands for the ohmic internal resistance, Rp for the polarized internal resistance, and Cp for the polarized capacitance.

Methods for the measurement of internal resistance of battery include DC discharge method and AC injection method. Compared with the DC discharge method, AC inserting method has the following advantages: (1) the measurement of the internal resistance of the battery is online, does not demand static or offline status. Therefore, the measurement avoids connection problems, and at the same time is able to get accurate and reliable measurement results. (2) The measurement avoids the accumulated damage to the battery performance caused by high-rate discharge compared with DC discharge method, and does not affect the safe operation of energy storage system. (3) The measurement does not require discharge load, and reduces the costs. This paper proposes a simple and reliable design as well as low costs. This module selects AC inserting method with the controlled current and put forward improving the method, enhancing the ability of processing analog signal.

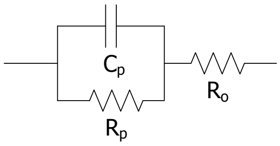

Fig.1. the simplifiedpractical model of internal resistance of batteries

When the controlled currentwas injected into the two terminals of the battery, the voltage response is

$$\Delta V = V_{\max} \sin(2\pi ft + \phi) \qquad (1)$$

Battery impedance is

$$Z(f) = (V_{\max} / I_{\max})e^{j\phi} \qquad (2)$$

Equation (2) shows that the measurement results of battery impedance is dependent on frequency, and the impedance modulus is

$$|Z| = V_{\max} / I_{\max} \qquad (3)$$

Assuming that the frequency of AC signal injected into the battery is ω, according to the simplified practical model of internal resistance of batteries as shown in fig. 1, the battery impedance is

$$Z = R_0 + \frac{R_p}{1+\omega^2 C_p{}^2 R_p{}^2} - j\frac{\omega C_p R_p{}^2}{1+\omega^2 C_p{}^2 R_p{}^2} \qquad (4)$$

When the frequency of AC signal injected into the battery stays between several hundred Hz and ten thousand Hz, the curve of AC internal resistance of battery is relatively stable. So the frequency of measurement signal should be selected within this range.

Equation (4) shows that if ω is smaller, the imaginary part of the internal resistance is closer to zero, $\omega C_P R_P$ in real part is closer to zero. So it is more convenient to remove the effect of capacitance which makes the pure impedance approximating to (R_O+R_P). In contrast, if ω is too big, the capacitance C is almost shorten, the measurement impedance values will completely ignore the polarized resistance – R_P, and it keeps the internal resistance of the battery closed to ohmic resistance – R_O. Experiment shows that the ohmic resistance of cathode is an important part of the whole cell impedance; ohmic resistance has influence on the battery capacity, the charge and discharge rate. As shown above, the measurement module chooses 1 KHz as the frequency of AC signal injected into the battery.

According to national standard GB/T 15100-2003/IEC 61436:1998, the module of battery impedance is equivalent to the ac internal resistance of battery. For this reason, this paper adopts internal resistance measurement through module of the impedance, which is achieved by calculating the peak of voltage response of battery.

The design of measurement module. Fig. 2 shows circuit structure of internal resistance measurement module. The sinusoidal voltage signal which is generated by the microprocessor unit is converted into sinusoidal current signal with the same frequency and phase through signal processing circuit and constant current source circuit, and outputs to the reference resistor and battery under test at corresponding time. The sinusoidal voltage response across the reference resistor and the batteries is converted into DC voltage signal through amplifying circuit， filter circuit and peak holding circuit. Dc voltage signal input to the microprocessor unit. The microprocessor unit compares the peak signal of voltage response from reference resistance with that of the battery measured, and calculates the internal resistance of the battery measured.

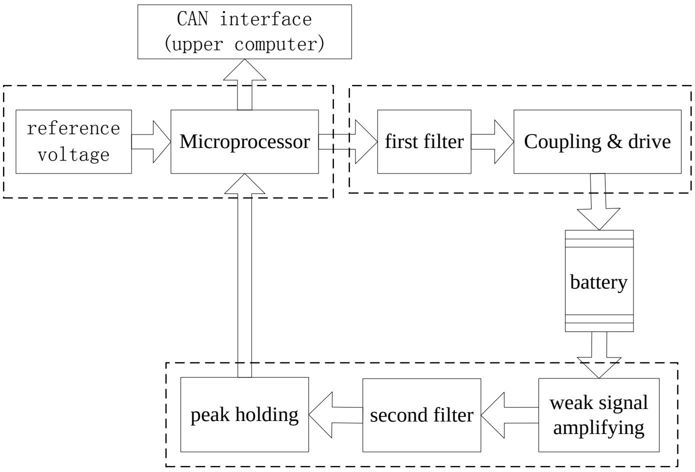

Fig.2. Circuit structure of internal resistance measurement module

On-chip 12-bit D/A converter of the microprocessor unit generates 1 KHz unipolar sinusoidal voltage signal. The signal is converted into bipolar sinusoidal voltage signal through adder, and is input to the first filter followed. The microprocessor acquires the peak response of battery through its internal 12 bit A/D converter, from which the internal resistance is obtained. The microprocessor also controls the constant current excitation signal and acquires peak signal to switch between the reference resistor and the battery under test.

The first and the second filter circuits are used to filter out the clutter and interference signal, and increase accuracy and stability of measurement. Filter circuit adopts a specific filter chip, and has the features of good dynamic characteristic, low noise, and high frequency precision.

Coupling and driving unit generates a stable constant current sinusoidal drive current with 50mA， and the drive current is injected to reference resistance and battery under test. The constant current driving circuit adopts the improved HOWLAND constant current source circuit which is composed by high voltage, large current integrated operational amplifier and low noise integrated operational amplifier. The improved HOWLAND constant current source circuit has high output voltage flexibility, and inhibits the oscillation caused by resistor mismatch.

The internal resistance of the battery is at the order of mΩ, as a result the voltage response signal of the internal resistance is at the order ofμ V and need be amplified with signal conditioning circuit for AD sampling. In the experiments the amplification effect of two cascaded amplifier circuits is better than that of high gain amplifier circuits composed by single operational amplifier, so amplifier circuit adopts two cascaded amplifier circuits respectively composed by precision instrumentation amplifier and low noise operational amplifier.

Peak holding circuit is composed by peak tracking circuit, peak holding capacitance and peak discharge circuit. CAN interface unit encodes the internal resistance data acquired and transmits the result of internal resistance measurement. CAN interface is also responsible for communication with the host or the main control unit of battery management system.

Calibration of the result of internal resistance measurement is achieved by switching measurement circuit between reference resistance and the battery been measured. In order to guarantee accuracy and stability of the sinusoid constant current source signal, the constant current source circuit employs high precision wire-wound resistor. The temperature drift of the wire-wound resistor is 25ppm/℃, whose precision is 1/10000. At the same time, the voltage response signal is measured using a four-wired for the purpose of reducing measurement error introduced by wires.

The software design of host. The labview is used to program host software. In order to facilitate real-time recording, storage and analysis of the internal resistance data, software mainly consists of communication module, dynamic display module and data storage module.

Communication module receives the data which is sent by CAN bus of internal resistance measurement module through the USB-CAN module, and decodes CAN bus data into internal resistance data according to the defined CAN protocol. Dynamic display module displays each measurement value of internal resistance and the overall variation curve in real time and dynamically in host software interface. User can monitor the internal resistance and the variation tendency of internal resistance in real time. The data storage module stores the received impedance data and measurement time by excel form, and facilitate the processing and analysis of resistance data.

Conclusion

This paper implements the practical engineering measurement system of internal resistance for lithium-ion battery which performs on-line measurement. Accuracy and stability of the measurement system are 0.29% and 0.26% respectively. On-line measurement system of internal resistance provides a new means for fault diagnosis of batteries besides monitoring of voltage, current and temperature of the battery manage system. It can also give new ideas for extremely dangerous fault diagnosis and performance prediction of batteries.

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