A New Method of Predicting the SOC of Lithium-ion Batteries

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Abstract—**The most important parameters of the battery management system are the state of charge(SOC) and state of health(SOH). The traditional method of estimating the SOC and SOH is to take measurement of the discharge current and the open circuit voltage. This paper proposed a new method of predicting the SOC which based on the measurement of dielectric loss angel. The method originated in the speculation that different state of charge batteries has different internal electrolyte distribution. In order to validate our point of view, a lot of experiment was done and got a series of convincing data. The preliminary experiment demonstrated that the SOC of Lithium-ion battery is in proportion to the Dielectric loss angle of internal medium to some extent.**

Keywords- SOC prediction; dielectric loss angel; Lithium-ion battery; Python

I. INTRODUCTION

With the smart phones, electric vehicles and different kinds of electronic products becoming more and more popular. The Lithium ion secondary batteries are now being used in wide applications. The reason why the Lithium-ion batteries are widely used is that they are light in weight, high in power, and long cycle in life etc[1].

With the rapid growth in demand for lithium-ion battery, Put forward higher requirements for the online management of the battery, the battery management system must has a battery SOC indicator, and temperature control and so on. The most important task of the battery management system is to get the current SOC and SOH, especially the SOC of the battery we are using accurately. In our real life, usually we want to know the SOC or the SOH of the battery in order to decide how to do and what to do next step. For example, we must know the SOC to determine the electronic vehicles whether can reach the destination or not, or the batteries must be disconnected because excessively discharged, and we also want to know the SOH of the batteries in order to make a decision that we should replace them or not. So, there is no doubt that, it is important to figured out the method which can get the SOC or SOH accurately whenever we want[2,3,4].

But the SOC or SOH of the battery related to a lot of external factors like the extent of discharge current, temperature, the number of discharged times and so on. Therefore the SOC or the SOH of the batteries can not represent with a fixed function, in other words, there is no definite relationship between them, that’s why it’s difficult for us to get these parameters[5].

The current method of measuring SOC is to get the voltage between the positive and the negative when the circuit is disconnected, and then compared with the data in the form previously. At present, almost all kinds of mobile phones are adopted this kind of method of measuring the voltage of the lithium ion batteries. This approach has a great deal of inaccuracy, ignored many factors. In this paper, the new method was proposed which based on the measurement of dielectric loss angle that by measuring the internal complex impedance of the battery, after that we can indirectly get the SOC or the SOH of the lithium ion batteries.

II. DIELECTRIC LOSS ANGLE STUDEIS

People commonly used the following three parameters to describe the dielectric properties: permittivity, tangent of the dielectric loss angle, and the Dc conductivity[6]. The following paragraph will explain to you the principle of this method.

When the medium is vacuum, the signal which was added between the two side of the medium is:

$$\mathrm{u} = U_0 e^{jwt} \tag{1}$$

The charge capacity of capacitor C_0 can be represented in the following formula:

$$Q = C_0 u \tag{2}$$

And the charge current is:

$$I_c = \frac{dQ}{dt} = j\omega C_0 u \tag{3}$$

When the medium is filled, the capacity of C_0 is increased to:

$$C = C_0 \frac{\varepsilon^{'}}{\varepsilon_0} = C_0 \varepsilon_r^{'} \tag{4}$$

The ε' is called as the permittivity of medium, and the ε_0 is called as the permittivity of vacuum, the ratio of them is called the relative Permittivity of the material. In addition to charging current I_c, but also a loss of current:

$$I_l = Gu \quad (5)$$

The total current is:

$$I = I_c + I_l = j\omega C + G \quad (6)$$

θ is the angel between I_c and I_l :

$$tg\theta = \frac{G}{\omega c} = \frac{1}{\omega RC} \quad (7)$$

Through all the formulas above, we can know that the tangent of the Dielectric loss angle is the ratio of the imaginary part and the real part of the complex impedance. In other words, if we get the complex impedance of the battery, we get the tangent of the dielectric loss angle.

III. OVERVIEW OF EXPERIMENT

The following block diagram is the guideline of our experiment. As all we know, the complex impedance of a object can be equaled to a serial of capacitor, resistor, and inductance, the location of R_x and C_x will be replaced with the lithium-ion battery.

A. The principle of experiment

The figure 1 shows the principle of this experiment. According to this schematic, the measurement circuit was designed

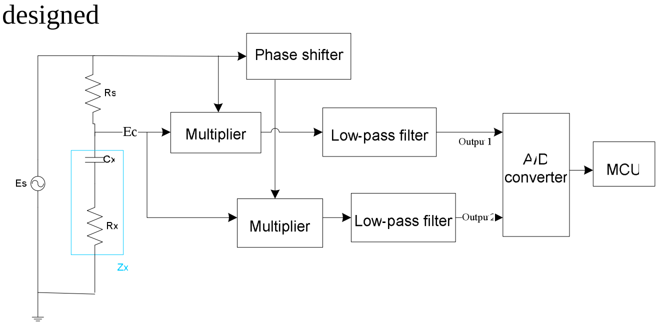

Figure 1. Schematic of SOC prediction

In figure 1, we know that the capacitance of the battery is very small compare to the internal impedance.

$$Eo = \frac{Rx + jXx}{Rs + Rx + jXx} Es \approx \frac{Es}{Rs} Rx + j\frac{Es}{Rs} Xx = Er + Ex \quad (8)$$

E_r is the in-phase component of E_s, the phase difference between E_x and E_s is $\pi/2$

$$Er = \frac{Es}{Rs} R_x \quad Ex = j\frac{Es}{Rs} Xx \quad (9)$$

This shows that the E_o contains the signal source E_s component(real part) and Ex which the phase difference is $\pi/2$ compared to E_s, and the active component Rx and inactive component Xx of the measured impedance Zx is respectively contained in the E_r and Ex, therefore, if we split the real part E_r and the imaginary part from the E_o, we can get the tangent of the dielectric loss angel. The output of the low-pass1(Output1) filter is in proportion to the real part of the E_o, and the output of the low-pass2(Output2) is in proportion to the imaginary part of E_o, so the ratio of the output1 and the output2 is the tangent of the dielectric loss angel.

B. Experiment steps

The procedure of our experiment is represented as following 5 steps:

1. Ensure that the two batteries are new, same series, and same state of charge, measured their voltage.
2. Discharge one of the two batteries a period of time with a constant current , and then measured the voltage.
3. Add the battery in the measuring circuit ,and adapt the signal frequencies, and then get the result.
4. Repeat the second step and the third step several times, the premise is to ensure that the battery's voltage is higher than it's cut-off voltage, otherwise, the battery will be damaged.
5. Write a program with python language to deal with all the experimental results.

C. Materials and details of experiment

The lithium-ion battery we used are Sanyo 18650 series, which are two identical cell ,output 3.7 v, 2600mAh, for the sanyo 18650 shown in figure 2. Experiment test were done for comparing the full state of charge battery and none full state of charge battery.

Figure 2. Lithium-ion sanyo 18650.

The climatic chamber and measurement device is illustrated in figure 2 and figure 4. The figure 3 (print circuit board) is designed for the test circuit based on the schematic(figure 1).

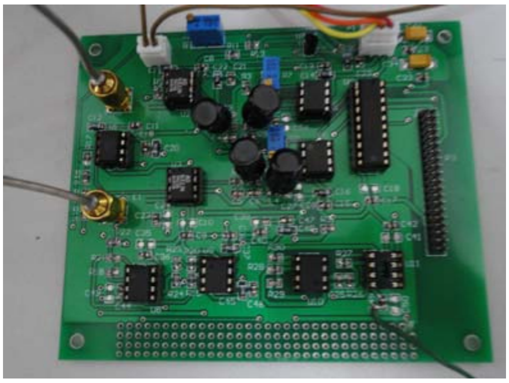

Figure 3. The printed circuit board we designed for experiment

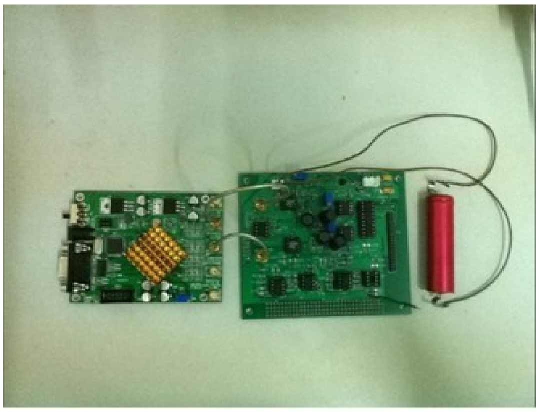

Figure 4. Climatic chamber and measurement device

The experiment result is shown in figure 5. We plot the data with a program which was written with Python language. Python is an object-oriented, dynamic programming language, which has a very simple and clear syntax. With the development of the Numpy, Scipy, Matplotlib, and so many modules, python becomes more and more suitable for scientific computing, draw 2D, 3D image effectively. Python is a general-purpose programming languages. Compare to the Matlab, it's widely used in many areas.

We represent the experiment result in the figure 5, as we see, there are three different kinds of curves, The solid line's source signal is 10MHZ, the dashed line is 5MHZ, and the dotted line is 1MHZ. From figure 5, we can see that the dielectric loss angle is in proportion to the voltage difference to some extent.

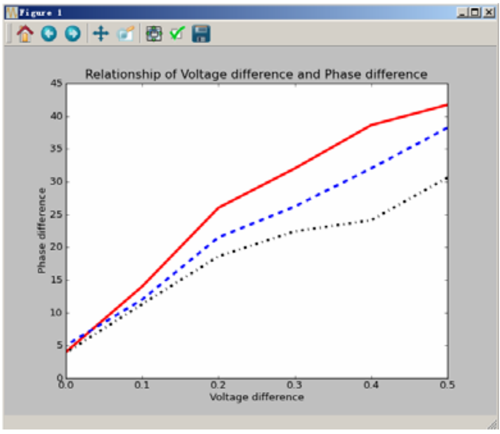

Figure 5. The relationship of voltage difference and phase difference

IV. CONCLUTION

In this paper, we have presented the new method predicting the SOC of Lithium-ion battery based on measuring the Dielectric loss angle. The experiment result illustrated that the SOC of Lithium-ion battery is in proportion to the Dielectric loss angle of internal medium to some extent. This explains that we can take measurement on the dielectric loss angle to predict the SOC of battery. In contrast to various traditional methods, the method in this paper is more accurate and can monitor the battery online. This provides a new method for monitoring the SOC and SOH of lithium-ion batteries. Further studies are needed to see whether this approach is suitable for different kinds of batteries, and whether it is accurate enough to be used in monitoring SOH and SOC of Lithium-ion batteries online.

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