Internal Resistance Computation of a Cylindrical LCO Battery for Heat Generation Model

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Abstract. The internal resistance is one of the most important parameters which directly relate to battery performance in terms of output power and heat generation. This research presents the internal resistance of the battery that is studied with using battery voltage behaviour. Lithium Cobalt Oxide (LiCoO2, LCO) battery is applied for the experiment. The voltage drop during the current discharge is calculated to obtain internal resistance by the current pulse technique (CPT). Three different terms of internal resistance are compared by the voltage drop characteristic. As the result, comparison of temperature profile between experiment and simulation was obtained by current pulse technique with discharge rate variations.

1. Introduction

The battery technology has been improved to make a new type of battery for supporting electronics. At the present, there are several battery types due to different materials. Most type of batteries include lead acid, lithium ion and Nickel batteries have different characteristics, advantages and disadvantages. Lithium Cobalt Oxide (LiCoO2, LCO) battery is a type of batteries that is used with many applications such as electronics, phones and laptops due to its high energy density but low power density [1]. However, one of the most important parameters of battery performance is the internal resistance. H. G. Schweiger et al. have explained that the internal resistance of battery is directly related to battery performance in terms of output power and heat generation; for example, the low internal resistance of battery provides higher output power but less among of heat generation compared to the high internal resistance [2]. The internal resistance of battery (R_{int}) includes three different terms of resistance; ohmic resistance caused by material, electrolyte and electrical connection (R_{ohm}), charge transfer resistance caused by the resistance of ion movement (R_{ct}), and diffusion resistance caused by the concentration within electrolyte between positive and negative pole (R_{d}) [3]. These three internal resistances trend to increase when the depth of discharge is higher. Moreover, the increase of the internal resistance affects to the battery heat generation. The heat generation of the battery includes two heat sources which occurs within battery: joule heating caused by current flow through the internal resistance of battery, entropy change caused by chemical activation within battery [4]. Therefore, the three terms of internal resistance should be accurately measured to find the heat generation of battery. In order to
obtain heat generation, the method to measure the heat generation due to entropy change using trial and error approach which can be used to model the battery heat generation [5]. The presented approach obtains the one term of internal resistance from measurement device which is not precise. Consequently, the exact heat generation ratio of those two heat sources is less accurate. This study represents a method to measure the three terms of internal resistance by battery voltage behavior. The voltage drop during the current discharge is calculated for the three terms of internal resistance. The result will be used for the heat generation simulation to compare the experimental and simulation temperature profile at 0.5C and 1C of the battery discharge rates.

2. Experiment Setup

2.1. Operating condition of battery cell and apparatus

As the heat generation of LCO is higher than other types of Lithium ion battery, and it is proper for the battery thermal study, 18650 Lithium Cobalt Oxide (LiCoO2, LCO) is used for the experiment [6]. The 18650 battery is 18 mm in diameter, 65 mm in the height and “0” represents the cylindrical shape as shown in figure 1. The battery cell is discharged in range of 4.2 V to 3.0 V as operating voltage and the discharge rates are determined at 1.3A (0.5C) and 2.6A (1C) as shown in table 1. using Agilent N3301A electronic load controlled via LabVIEW software which is used to determine among of current and time for the current pulse pattern. The Graphtec midi Logger GL840 data logger is used to measure battery voltage and battery surface temperature.

![Figure 1. Experimental equipment a)18650 LCO battery cell b) Data acquisition unit.](image)

| Table 1. Specification of Lithium ion cell [7] |
|-----------------------------------------------|
| Cell Chemistry               | Cell Geometry     | Size (mm.) | Operating Voltage (V) | Nominal Capacity (mAh) |
| Lithium Cobalt Oxide (LiCoO2) | Cylindrical       | 18 (D)     | 4.2 ~ 3.0             | 2600                  |
|                               |                   | 65 (H)     |                        |                       |
3. Methodology

3.1. Current Pulse Technique
Lam L. explains the three terms of internal resistance can be expressed by equation (1)[2]. To investigate the three terms of internal resistance, Current Pulse Technique (CPT) is applied to obtain the internal resistance of the battery. The current pulse (see in figure 2) is used for the discharging. The battery is applied for load in one minute which decreases for 1.67% of state of charge (SOC). Then, it is rested for three minutes to restore the close circuit voltage (Vcc) of the battery to the open circuit voltage (Voc) state. In addition, Lam L. has presented the internal resistance is directly related with % SOC, it increases at high % DoD[2]. Therefore, from the current pulse pattern in figure 2, the battery capacity is removed from 0%–100% state of charge and the voltage characteristic is displayed as shown in figure 3 to obtain the three terms of internal resistance at 0–100% state of charge.

\[
R_{\text{int}} = R_{\text{ohm}} + R_{c_{\text{ch,tr}}} + R_d
\]  

(1)

3.2. Internal resistance calculation
From section 3.1, the CPT is applied to obtain voltage characteristic for studying the three terms of internal resistance. Therefore, Thanagasundram S, Arunachala R, Makinejad K, Teutsch T, and Jossen A have presented the internal resistance calculation from the voltage drop as shown in figure 4[8]. The voltage is distinguished into two main parts. The first part is the voltage drop from \(u_1\) to \(u_2\) caused by the Ohmic resistance \(R_{\text{ohm}}\) and the diffusion resistance \(R_d\). This instant drop can be calculated from equation (2). The second part is the effect of charge transfer resistance \(R_{c_{\text{ch,tr}}}\) which behaves like the capacitor. Consequently, it causes the curve after instant drop from \(u_2\) to \(u_3\). The end of \(u_3\) is determined by the rate of voltage change by time less than 0.001 V/s\(^2\). This algorithm can be done using MATLAB software as the tool. The charge transfer resistance can be calculated from equation (3).

\[
R_{\text{ohm}} + R_d = \frac{(u_1 - u_2)}{i}
\]  

(2)

\[
R_{c_{\text{ch,tr}}} = \frac{(u_2 - u_3)}{i}
\]  

(3)
Figure 2. Current pulse technique (CPT) for discharging.

Figure 3. Battery voltage using current pulse technique.

Figure 4. The voltage drop characteristic during discharging for calculation.
4. Result and Discussion

4.1. Internal resistance

The internal resistance of the battery is presented by two parts according to the calculation approach. At the first part as shown in figure 5, the Ohmic resistance and diffusion resistance are fairly constant at 0–60% DoD, then significantly increase after 60% DoD. The increase is caused by owing to the diffusion resistance term. The concentration gradient in the electrolyte becomes higher when the battery capacity is low. Therefore, it enhanced the resistance of the ion movement which increases the diffusion resistance.

For the second part as shown in figure 6, the behaviour is similar to the first part but causes by the different reason. In this scenario, at 0–60% DoD, the ions can easily perform the chemical reaction at the electrode to generate to the electricity, therefore the charge transfer resistance is quite constant. At the end of discharge state, after 60% DoD, the surface area of electrode is insufficient to perform the reaction because the activated ions form at the electrode surface as the layer and resist the moving ions to reach the electrode. Thus, the charge transfer resistance is higher at the end of discharge state.

![Figure 5](image5.png)

**Figure 5.** The Ohmic resistance ($R_{ohm}$) and diffusion resistance ($R_d$) at 0 – 100% DoD.

![Figure 6](image6.png)

**Figure 6.** The charge transfer resistance ($R_{ch,tr}$) at 0 – 100% DoD.
4.2. Thermal behavior
The heat generation of battery includes two heat sources as joule heating and entropy change which can be expressed by equation (4). The joule heating and entropy change can be expressed by equation (5) and equation (6) respectively [3].

\[ Q_{battery} = \dot{Q}_{joule} + \dot{Q}_{entropy} \]  
\[ \dot{Q}_{joule} = I^2 \cdot R_{int} \]  
\[ \dot{Q}_{entropy} = -iT \cdot \left( \frac{\Delta S}{nF} \right) \]

**Figure 7.** Battery surface temperature profile of experimental and simulation during constant current discharge at 1.3A (0.5C).

**Figure 8.** Battery surface temperature profile of experimental and simulation during constant current 2.6A (1C).
The experimental is discharged at 0.5C and 1C. From discharged current at 0.5C, the experimental result as shown as the dot line in figure 7. It represents that the maximum battery surface temperature which reaches 30.6°C. It comes from two heat sources. To analyse the contribution of two heat sources separately, simulation using Finite Element Method (FEM) is needed. the joule heating heat source is computed by equation (5) which use the internal resistance calculated from section 4.1. the simulation result as shown as dash line in figure 7. It is less than the experimental result because it comes from only joule heating heat source. Therefore, the temperature gap between joule heating temperature profile (dashed line) and the experimental (dot line) is considered as the heat source from the heat generation due to entropy change. To complete the temperature profile, the heat source from entropy change is used the trial and error method can be expressed by equation (6) which be similar method of Chanthevee P et al [4]. Thus, the simulation result which combines both joule heating heat sources and entropy change as shown as black line in figure 7. In addition, the experimental result and simulation result at 1C are represented as shown in figure 8, respectively.

5. Conclusion

5.1. Internal resistance calculation
This current pulse technique can be used for the internal resistance of the battery using the current pulse pattern for discharging and the voltage drop for the calculation. The result of the internal resistance calculation consists of three different internal resistance of terms which can be used for heat generation simulation. Thus, this current pulse technique (CPT) can be applied for various discharge rate using the similar current pattern and calculation.

5.2. Thermal behaviour
The internal resistance obtained from the current pulse technique is more precision than measuring from device because the temperature trend of joule heating is like the experimental result. Consequently, the heat source contribution of this paper is difference compared to the of Chanthevee P et al. It is because the internal resistance measurement of this paper includes the effect of three different terms of the resistance. Thus, the temperature of joule heating is relatively higher. Thus, this is more practical for the battery heat generation modelling.

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