ISSN 2616-7433 Vol. 6, Issue 6: 81-85, DOI: 10.25236/FSST.2024.060613

Research on Calculating the Internal Resistance of Battery Cell

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Abstract: *Internal resistance can be thought of as a measure of the "quality" of a battery cell. A low internal resistance indicates that the battery cell is able to deliver a large current with minimal voltage drop, while a high internal resistance indicates that the battery cell is less able to deliver a large current and experiences a larger voltage drop. Internal resistance can be affected by various factors, including: the type and composition of the electrodes, the temperature of the cell, and the state of charge of the cell. It can also vary depending on the discharge rate, with higher discharge rates typically resulting in a higher internal resistance. Calculating the internal resistance of a battery cell can be useful for determining the performance of the cell and identifying any issues that may affect its performance. This article takes the Panasonic NCR18650B battery cell as an example, proposes a circuit model and calculation formula for calculating the internal resistance of the battery cell, and the calculation results are reliable, providing an effective approach for the calculation and research of battery internal resistance.*

Keywords: *battery cell, internal resistance, circuit model, calculation method*

1. Introduction

Battery cell internal resistance, measured in ohms (Ω), reflects the resistance to current flow within the cell. It serves as an indicator of the battery cell's performance. A lower internal resistance suggests the ability to provide a substantial current without significant voltage drop, while a higher internal resistance indicates a reduced capacity to deliver a large current and a higher voltage drop. Multiple factors influence internal resistance, such as electrode type and composition, cell temperature, and state of charge. Additionally, discharge rate can also impact internal resistance, with higher rates generally resulting in increased resistance.

Measuring a battery cell's internal resistance is important for assessing its performance and identifying potential issues. The internal resistance of lithium-ion cells typically ranges from a few mΩ to a few hundred mΩ, depending on the type and design. For instance, high-performance lithium-ion cells designed for rapid discharge may have an internal resistance of approximately 50 mΩ, while lower-performance cells for slower discharge may have around 200 mΩ. In the case of lead-acid battery cells, the internal resistance is generally within the range of a few hundred mΩ to a few thousand mΩ. For example, a deep-cycle lead-acid battery used in electric vehicles may have an internal resistance of around 500 mΩ, while a high-rate discharge lead-acid battery could have an internal resistance of about 1000 mΩ. Similarly, nickel-metal-hydride (NiMH) battery cells can exhibit internal resistance ranging from a few hundred mΩ to a few thousand mΩ. A high-capacity NiMH battery cell designed for electric vehicles may have an internal resistance of approximately 1000 mΩ, while a high-rate discharge NiMH battery could have an internal resistance of around 2000 mΩ. It is common for battery cell manufacturers to provide internal resistance information in their datasheets. This information proves valuable to designers and engineers who are selecting batteries for specific applications as it helps them understand the cell's performance characteristics and how it may behave under different conditions.

The internal resistance of a battery cell is typically given as a static value, representing its resistance at a low discharge rate (typically around 0.2C or lower). However, at higher discharge rates, the internal resistance may increase[1]. In some cases, the datasheet may include information on the internal resistance of the cell at different discharge rates. This can be helpful for understanding the cell's performance across a wider range of conditions.

If the manufacturer does not provide the internal resistance value, it is possible to calculate it based

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on the discharge characteristics of the battery cell. By analyzing the cell's behavior at a specific state of charge, we can determine its internal resistance. This calculation method will be discussed further in this article.

2. C-rate | Discharge Current (mA) | Discharge Time (hours)

In the table 1, we have a battery cell with a capacity of 3200 mAh. The C-rate indicates the discharge current at different multiples of the cell's capacity. For instance, at 1C, the cell is discharged at a current of 3200 mA, which would result in a discharge time of 1 hour to fully deplete the cell's capacity. At 2C, the discharge current is doubled to 6400 mA, resulting in a discharge time of 0.5 hours or 30 minutes. Similarly, at higher C-rates, the discharge current increases, leading to shorter discharge times.

It is important to note that the C-rate can affect the performance and lifespan of the battery cell[2]. Discharging at higher C-rates can generate more heat and increase the internal resistance, potentially reducing the overall capacity and lifespan of the cell. Therefore, it is crucial to consider the recommended C-rate for a battery cell to ensure optimal performance and longevity.

Table 1. Discharge current and discharge time at different C-rate

C-rate	Discharge Current (mA)	Discharge Time (hours)
0.2C	0.2 · 3200 mAh = 640 mA	3200 mAh / 640 mA = 5 hours
0.5C	0.5 · 3200 mAh = 1600 mA	3200 mAh / 1600 mA = 2 hours
1C	1 · 3200 mAh = 3200 mA	3200 mAh / 3200 mA = 1 hours
2C	2 · 3200 mAh = 6400 mA	3200 mAh / 6400 mA = 0.5 hours

The C-rate of a battery cell is an important factor that can affect its performance and lifespan. Higher C-rates can allow for faster charge and discharge times, but they can also contribute to a shorter overall lifespan of the cell due to increased stress on the electrodes and other components[3].

It's crucial to understand that the specific C-rate capabilities of a battery cell can vary depending on factors such as its design, chemistry, temperature, and state of charge. Some battery cells may be able to handle higher C-rates without significant degradation, while others may be more sensitive to higher C-rates and experience more wear and tear.

3. Battery cell discharge characteristic

The discharge characteristic of a battery cell refers to how its voltage and capacity change during the discharge process. This characteristic is crucial in determining the cell's performance and can vary based on factors such as cell type, design, chemistry, and discharge conditions.

Generally, the voltage of a battery cell decreases as it is discharged. The rate at which the voltage decreases depend on the load placed on the cell and its state of charge. For instance, a cell discharged at a high rate (high C-rate) may experience a more rapid voltage drop compared to a cell discharged at a low rate.

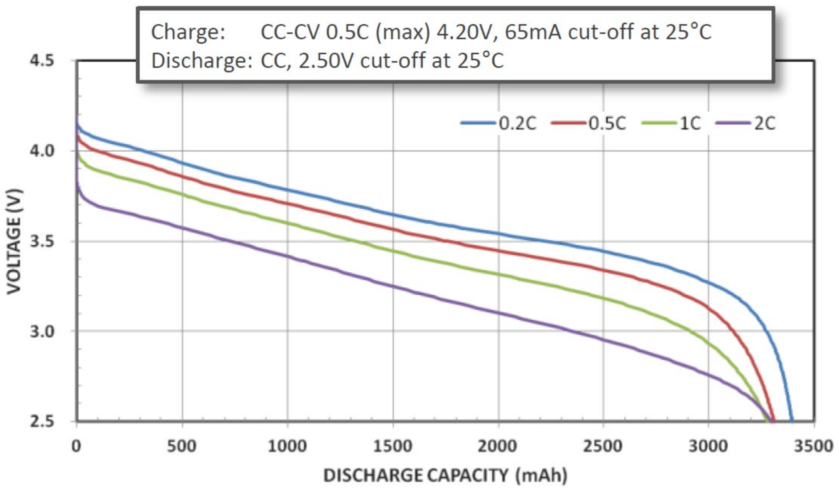

Figure 1: Panasonic NCR18650B discharge characteristic

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The capacity of a battery cell decreases as it is discharged, as shown in Figure 1. This decrease depends on factors like the cell's design, chemistry, discharge rate, and temperature. Capacity is measured in milliampere-hours (mAh) and represents the energy the cell can deliver over time.

For instance, consider a lithium-ion battery cell with a 1000 mAh capacity. Discharging at 1C (1000 mA) will fully deplete the cell in around one hour. Doubling the discharge rate to 2C (2000 mA) will fully deplete the cell in approximately half an hour.

4. Battery cell internal resistance circuit model

The battery cell circuit model is a mathematical representation of how a battery cell behaves in an electrical circuit, as shown in Figure 2. It takes into account the internal resistance (R_i) of the cell in milliohms (mΩ), the open circuit voltage (E) in volts (V), and the terminal voltage (U) in volts (V), the relationship is shown in equation 1.

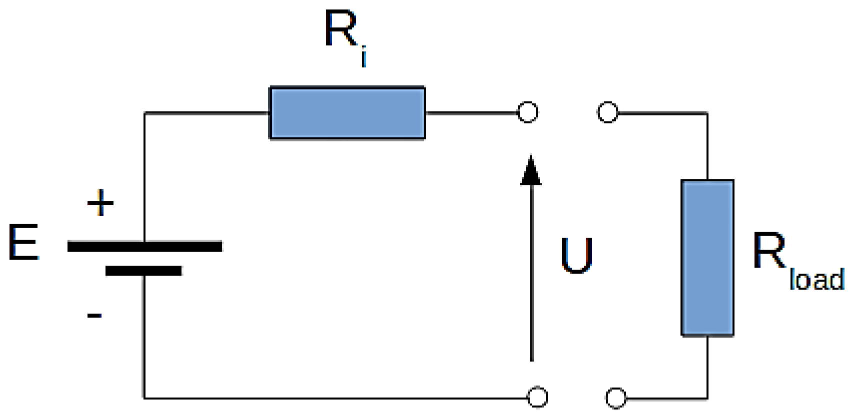

Figure 2: Battery equivalent electrical circuit.

The internal resistance (R_i) of a battery cell, measured in milliohms (mΩ), indicates how much the cell resists the flow of current. Factors such as the cell's electrode material, electrode thickness, and electrolyte's ionic conductivity contribute to its internal resistance. The internal resistance affects the cell's performance and efficiency, typically increasing at higher current densities and lower temperatures.

The open circuit voltage (E) of a battery cell, measured in volts (V), refers to the cell's voltage when not connected to any external load. It represents the cell's electrochemical potential and is influenced by factors like the cell's state of charge, temperature, and age. The terminal voltage (U) of a battery cell, measured in volts (V), is the voltage measured at the cell's terminals when it is connected to an external load. It is obtained by subtracting the voltage drop caused by the cell's internal resistance and the external load from the open circuit voltage. The electrical current (I), measured in amperes (A), refers to the current that flows through the internal resistance when a load is connected to the battery cell.

$$U = E - I \cdot R_i \tag{1}$$

The battery cell circuit model is a valuable tool for predicting the voltage, current, and state of charge of the cell in various conditions, including different load currents and temperatures. This model is particularly useful in applications like battery management systems, where an efficient and precise representation of the cell's behavior is necessary. By utilizing the circuit model, it becomes possible to quickly and accurately assess the performance and behavior of the battery cell.

5. Internal resistance calculation

If we have the discharge characteristics of a battery cell, for different values of the C-rate, we can calculate the internal resistance of the battery cell at a specific state of charge (SOC) [4].

As an example, we are going to use the Panasonic NCR18650B lithium-ion battery cell which has a nominal capacity of 3200 mA and the discharge characteristics as shown in Figure 3 [5].

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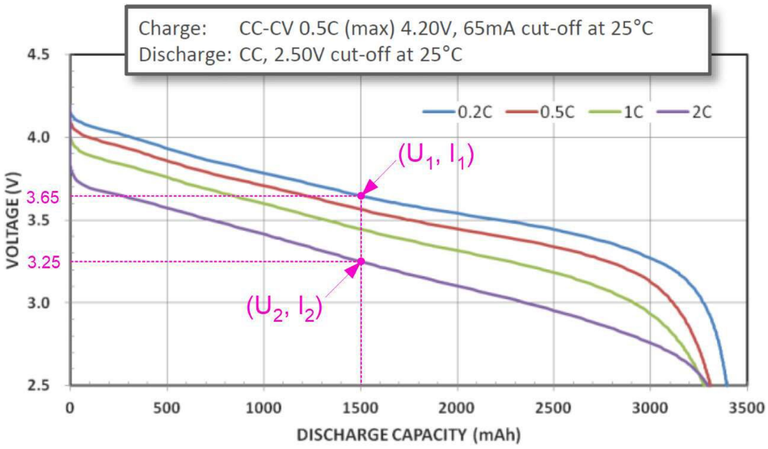

Figure 3:Panasonic NCR18650B internal resistance calculation

We aim to calculate the internal resistance of the cell at approximatively 47 % state of charge (SOC).

Step 1. Calculate the discharge capacity of the battery cell for 47 % SOC. Since the nominal capacity of the battery cell is 3200 mA, which corresponds to 100% SOC, at 47% SOC, the battery cell capacity would be:

$0.47 \cdot 3200 = 1504$ mAh ≈ 1500 mAh

Step 2. Read the terminal voltages for 2 selected discharge curves at the calculated discharge capacity of 1500 mAh. We are going to select the 0.2C and 2C discharge curves, for which we can read from the image above the terminal voltages:

$U_1 = 3.64689$ V

$U_2 = 3.24647$ V

Step 3. Calculate the current through the internal resistance for both discharge curves:

$I_1 = 3200 \cdot 0.2 = 640$ mA $= 0.64$ A

$I_2 = 3200 \cdot 2 = 6400$ mA $= 6.4$ A

Step 4. Apply equation (1) for the equivalent circuit model for both 0.2C and 2C discharge curves and solve for R_i (Ω).

$3.64689 = E - 0.64 \cdot R_i$

$3.24647 = E - 6.4 \cdot R_i$

By subtracting the second equation from the first equation we get:

$0.40042 = R_i \cdot (6.4 - 0.64)$

which gives the internal resistance:

$R_i = 0.06952\ \Omega = 69.52\ m\Omega$

Conclusion: The internal resistance of the battery cell is approximately 69.52 mΩ at 47% state of charge.

6. Open circuit voltage calculation

The calculation of the open circuit voltage E [V] is fairly simple, now that we know the value of the internal resistance of the battery cell.

Using the values U_1 and I_1 for the 0.2C discharge curve, we can write equation (1) as:

$3.64689 = E - 0.64 \cdot 0.06952$

Solving for E, gives the value of the terminal voltage:

$E = 3.64689 + 0.0444928 = 3.6913828$ V

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when the battery cell is discharged with 640 mA at 47 % state of charge.

7. Power loss calculation

Having the internal resistance of the battery cell, we can calculate the power loss P_{loss} (W) for a specific current as:

$$P_{loss} = I_2 \cdot R_i \tag{2}$$

For example, at 47 % SOC, if the output current is 5 A, the power loss of the battery cell would be:

$P_{loss} = 52 \cdot 0.06952 = 1.738$ W

8. Conclusions

This article takes the Panasonic NCR18650B lithium-ion battery as an example, and calculates the internal resistance, open circuit voltage, and power loss of the battery based on the circuit model and calculation equations. The calculation results are reliable, and the following conclusions are drawn:

The internal resistance of a battery cell plays a crucial role in an electric vehicle's (EV) battery pack performance. High internal resistance can negatively affect both the overall capacity and efficiency of the pack. The internal resistance causes a voltage drop within the cell, leading to overheating and reduced performance.

Moreover, the internal resistance of a battery cell has an impact on the charging and discharging rate, which directly influences the overall performance of the battery pack. A high internal resistance can result in a slower charging process and a reduced ability of the pack to discharge efficiently. This limitation in charging and discharging speed can have implications for the optimal functioning of the battery pack.

On the other hand, a battery pack with low internal resistance in its cells typically exhibits superior performance. It enables faster and more efficient charging and discharging processes. This enhanced capability allows for improved overall performance of the battery pack.

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