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Li-NMC Battery Internal Resistance at Wide Range of Temperature

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ABSTRACT

One of the factors that affects energy transfer by Lithium-ion batteries is internal resistance. This internal resistance occurs due to resistivity of the electrochemical materials and its ionic component. Meanwhile, the internal resistance of a battery is affected by several factors such as temperature and their state of charge. To maintain battery health and prevent rapid degradation, the use of batteries at high temperatures should be avoided. In that relation, studies involving battery internal resistance are mostly conducted in an ideal temperatures range. This makes data on internal resistance at high temperatures scarce and insufficient. Accordingly, this internal resistance data is an important key component in predicting the battery temperature. Good internal resistance data at high temperatures can contribute to a more accurate battery temperature prediction. The purpose of this study is to provide internal resistance data for Li-MNC battery in wide range of temperature by means of experiment. In this study, the temperature of Lithium-ion Manganese-Nickel-Cobalt (Li-MNC) battery with the capacity of 40Ah was raised via high current discharge method. The discharge current used was 120A (3C) and 160A (4C). The discharge temperature was conducted from 26°C to 80°C. Internal resistance is then calculated from the measured voltage respond when 1C (40A) pulse current discharge flow through the battery. Results showed that as temperature increases, the value of internal resistance decreases. At the same time however, the rate of decrement declined until it become almost constant at high temperature range until reaching 80°C. The objective of this study is to provide the data of battery internal resistance at a wide temperature range up to 80°C. This information is important in developing a precise battery electro-thermal model that can predict battery performance and temperature. On the extend of that, this information will be useful in developing better battery management system to ensure good battery usage and safety.

1. Introduction

Internal resistance is a concept where a flow of current is opposed within the battery [2]. When the movement of electrons are obstructed along the circuit path, it is subjected under a certain amount of resistant. There are variety of batteries available nowadays including non-rechargeable

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such as cadmium battery, nickel battery and rechargeable battery including Lithium-ion battery (LIB). Other than chemical-based battery, there is also bio-based battery in development such as microbial fuel cell that is used in electricity generation [16]. In the effort to pursue green energy and clean renewable energy to tackle energy security issue as one of the concerns by the European Union, research in this area is begun to bloom [5]. Sustainable energy plan was also being actively discussed in Malaysia [18]. As an example, research to harvest small-scale electricity generation by taking advantage of rainwater impact on piezoelectric cells was done by Roy *et al.,* [17]. Meanwhile, in neighbouring country such as Indonesia, an effort to reuse biowaste such as rice husk as renewable energy was thoroughly researched [10]. One of the proactive efforts of migrating to green energy can be seen in the plantation sector where tractors are begin adopting hybrid vehicle technology that uses electrical power with the advantages of saving fuel consumption [3,13]. Back to the main topic, amongst rechargeable battery, LIB is widely used in electric vehicles, smartphones and laptops because of good stability with high power density and low self-discharge [11,15,20]. In LIB, the internal resistance occurs due to resistivity of the component materials and its ionic component due to electrochemical factors such as electrolyte conductivity, ion mobility and electrode surface area [1]. The value of internal resistance changes depending on the battery temperature. Zhang *et al.,* [24] shows the relationship between internal resistance and temperature in their study. Battery with different values of SOC were tested and the result shows that internal resistance decrease as temperature increase. The rate of internal resistance declines fast at low temperature and became slow as the temperature rises. The known behavior of battery internal resistance is that it decreases as the battery temperature increase. Most study about battery internal resistance and its thermal properties stops below or at the ideal battery condition. Table 1 shows past study of LIB internal resistance and temperature parameter set. From Table 1, it shows that most study were conducted in normal operating temperature. The highest temperature parameter used was by Noelle *et al.,* [14] which was 63°C. The gap in knowledge for this study is to know what happen on the battery internal resistance when the battery is operated beyond normal operating condition. This paper will first present the methodology used to get the internal resistance data and then goes to experiment results with discussion and finally conclusion to summarize the research.

Table 1
List of LIB internal resistance study

Author	Temperature parameter (°C)
Karevs *et al.,* [4]	20
Kisu *et al.,* [6]	25
Łebkowski [7]	-30 ~ 55 (5° interval)
Li *et al.,* [8]	30~ 60
Madani *et al.,* [12]	30
Noelle *et al.,* [14]	23~63
Piłatowicz *et al.,* [16]	0~25
Schweiger *et al.,* [19]	25

2. Experimental
2.1 Experimental Setup

The test battery is wired with 2 high amp cable at both side of the terminal. Table 2 shows the battery descriptions. Three RTD sensors, labelled as sensor 1, sensor 2, sensor 3 are attached 30 mm away from anode terminal, in the middle of the battery, and 30 mm away from cathode terminal respectively as seen in Figure 1. Along with that, 2 wires are attached at anode and cathode terminal to detect the potential difference when discharging with pulse current. The wire will be feed into data acquisition system.

Table 2
Battery descriptions

Description	Dimension
Battery type	Lithium-ion Manganese-Nickel-Cobalt (Li-MNC)
Battery height	236 mm
Battery width	188 mm
Battery thickness	8 mm
Capacity	40 Ah
Nominal voltage	3.7 V
Specific heat capacity	304 J/Kg°C
Battery mass	0.8 Kg

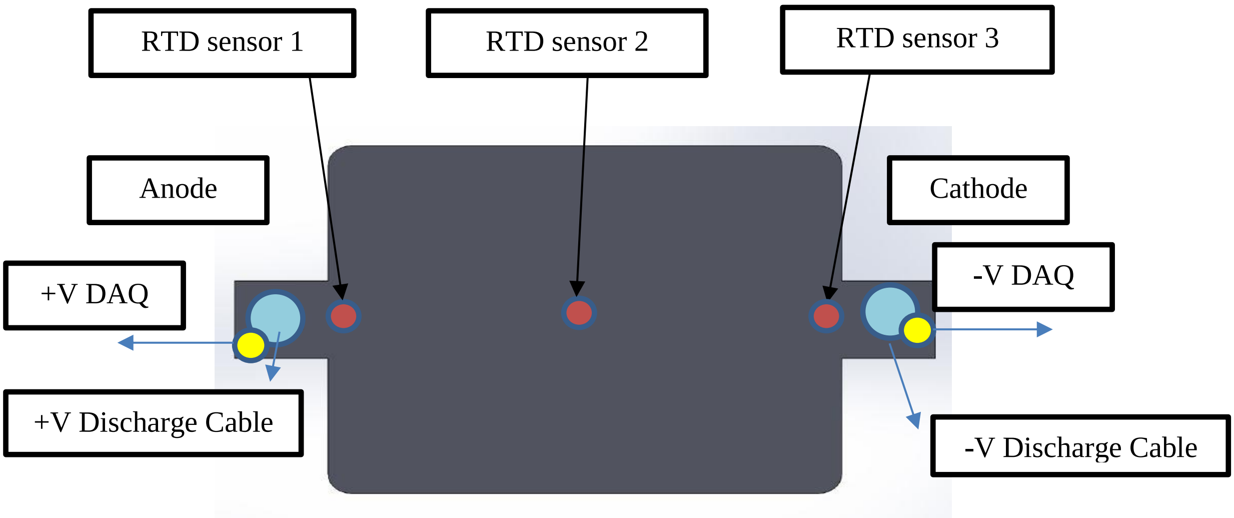

Fig. 1. Battery setup

The system which is used to control the battery charging and discharging current are as in Figure 2. The battery will be charge with ITECH IT6502D Power Supply and discharge with ITECH IT8514C+ Electronic Load. Current charging and discharging level can be set manually beforehand.

Fig. 2. (A) ITECH IT6502D Power Supply; (B) ITECH IT8514C+ Electronic Load

All data acquisition including battery temperature and voltage are conducted through cDAQ-9178 from National Instruments which are linked to LabVIEW software in a computer. The data can be recorded and observed in real time. Figure 3 shows NI cDAQ-9178.

Fig. 3. National Instrument CompactDAQ-9178

2.2 Experimental Procedure

The goal of this procedure is to raise the battery temperature by discharging the battery with high discharge current using ITECH IT8514C+ Electronic Load. Since the capacity of the battery used in this experiment has 40 Ah capacity, 1C discharge current will be 40 A. For safety reason, the selected discharge current will be cap at 4C which is 160 A. But to consider SOC effect on the internal resistance, the SOC of the battery need to be maintained above 20%. Using 1C or 2C discharge current will not be sufficient enough to raise the battery temperature beyond normal operating condition before the battery SOC depleted below 20%. Hence, for the normal operating temperature, 3C (120A) will be used to discharge the battery. For beyond normal operating temperature (>70°C), 4C (160A) discharge current will be used. The battery that will be discharge has been make sure to be in fully charged state. ITECH IT6502D power supply was used to slowly charge the battery until 100% SOC with 0.125C (5A) charging current at 4.20V constant voltage. The charging process will stop automatically when the battery is full where the battery voltage is equivalent to the supply voltage and no current flow (0A).

The temperature parameter at which the battery is tested will start from 40°C and increasing in 5°C until the highest achievable temperature that can be reached by the system or by the battery (which ever come first). Although the interested testing temperature parameter are at high temperatures range, several internal resistance data at low temperature are also needed as a result benchmark. For that, 26°C (room temperature) and 30°C are included as well. For gathering internal resistance data, the battery will be tested according to adjusted HPPC method by PNGV battery test manual 2001 as stated in chapter 2. 1C (40A) pulse current will be discharge from the battery to record the voltage respond. The before and after voltage respond data is analyze to make internal resistance calculation. After all necessary data were taken, the battery is cooled by force convection to preserve the battery health and prevent faster degradation by heat.

By using Ohm's Law, R_{int} can be calculated by using the value difference of voltage at initial state and voltage measured when current pulse pass through the battery as shown in Eq. (1) [9,19,21]. This is the most adopted method to calculate dc resistance by some battery manufacturer which is now assumed as the standard of dc resistance measurement [25].

$$R_{int} = \frac{V_2 - V_1}{I_2 - I_1} \tag{1}$$

3. Results and Discussion

By following the experiment procedure, a total of 11 tests were successfully achieved. The discharge test was run at 26°C (room temperature), 30°C, 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, 70°C, 75°C, 80°C. A total of 11 voltage responds successfully recorded for internal resistance calculation data.

Figure 4 shows the Internal resistance and temperature data for the Li-NMC battery obtained from experiment. The values for each internal resistance value are as in Table 3 below. From the figure, it can be observed that as temperature increases, the value of internal resistance decreases. But the rate at which internal resistance decreasing are getting smaller and almost became constant at high temperature range as can be seen in temperature 70°C to 80°C. In addition, the trendline of the graph in the figure is close to inversely proportional.

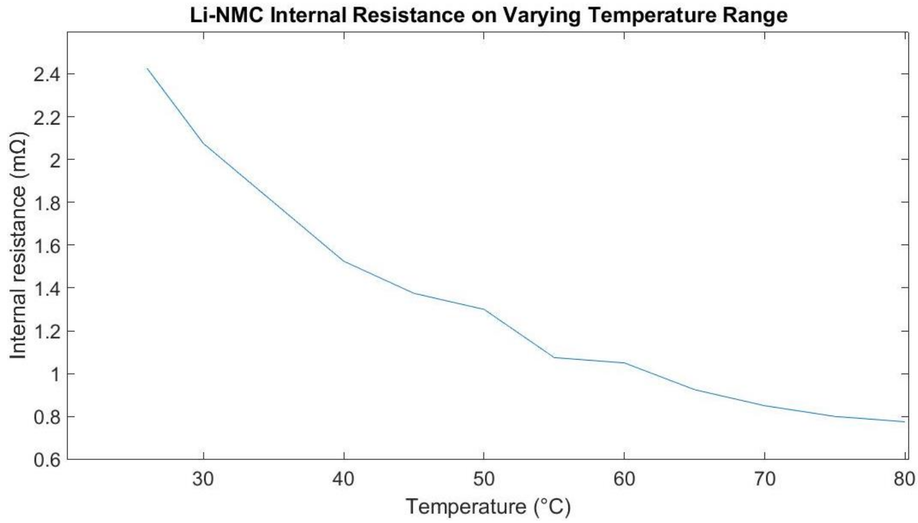

Fig. 4. Battery internal resistance at varying temperature

Table 3
Internal resistance at different temperature

Temperature (°C)	Internal resistance (mΩ)
26	2.425
30	2.075
40	1.525
45	1.375
50	1.300
55	1.075
60	1.050
65	0.925
70	0.850
75	0.800
80	0.775

From the graph of internal resistance and temperature in Figure 4, compared to the findings of other research papers by Łebkowski [7] as in Figure 5 and Lou *et al.,* [9] in Figure 6, it can be agreed that the trend of internal resistance to its temperature point in this study is similar as temperature increase, internal resistance decrease. This trend was expected to be occurred because lithium diffusitivity increased as the temperature increased which enhanced ion mobility and electrolyte conductivity in LIB as agreed by Ye *et al*., [23] and Bhargava [1]. The difference of this study from Łebkowski [7] and Lou *et al.,* [9] is that the parameter for temperature testing used as a manipulated variable is much higher. However, the value of internal resistance continues to decrease even though the testing temperature is on a scale beyond normal operating temperature. Indirectly, the similarity of the findings of this study with the research papers by Łebkowski [7] and Lou *et al.,* [9] can be used as confirmation that the results of internal resistance and temperature in this study can be accepted.

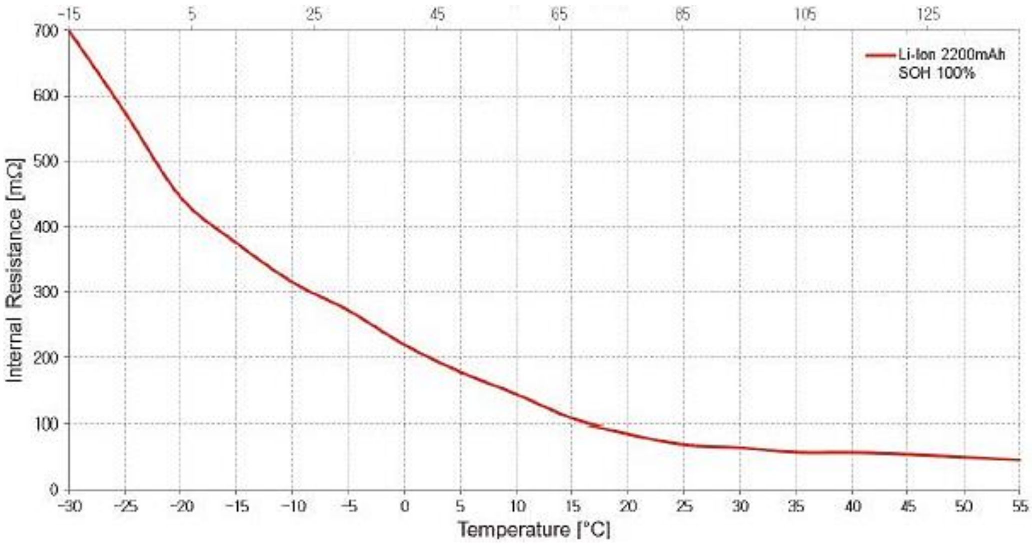

Fig. 5. Internal Resistance profile [7]

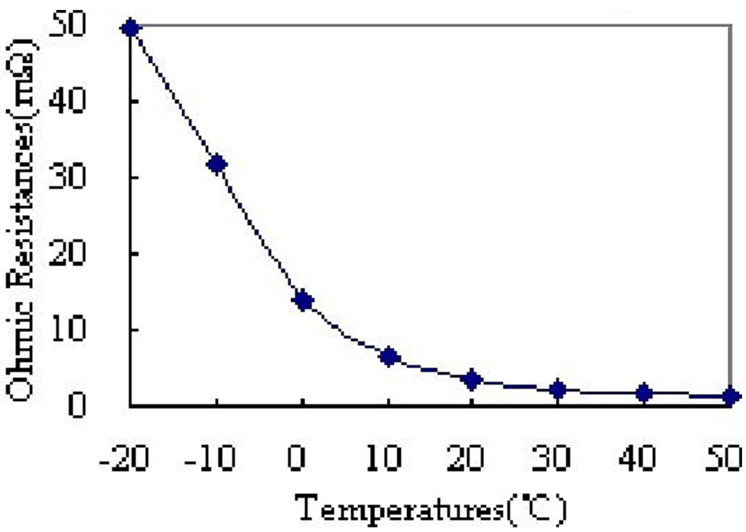

Fig. 6. Internal resistance against temperature [9]

4. Conclusion

From this study, it can be concluded that the value of internal resistance decreases as the temperature increases. Although the battery temperature has reached beyond normal operating conditions, the trend in decreasing internal resistance as the temperature rises remains to hold true. As observed in this study, the value of internal resistance decreases drastically from 26°C to 74°C then remains almost constant when temperature past 75° to 80°C. The relationship between battery internal resistance and temperature shows that the objective in this study has been achieved. This study has contributed a little bit to the knowledge of batteries application at high temperatures. Data on internal resistance and battery thermal behavior can certainly be used during designing process of battery for a better high temperature use. Accordingly, the simulation consisting of electro-thermal models in this study can help to build a better battery management system that can control battery performance on a wide range of battery temperatures. This study can be continued for future works by expanding the study to various types of batteries other than lithium ions. The methodology used in this study can certainly contribute to worthful research findings.

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