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ANALYSIS OF VOLTAGE DROP-IN HIGH-POWER LITHIUM-ION BATTERY DURING CHARGE & DISCHARGE CYCLES AT DIFFERENT C-RATES & TEMPERATURES

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ABSTRACT

Globally, electric automobiles (EVs) are the newest and most innovative technology in the transportation industry. Their decreasing consumption of fuel and emissions of greenhouse gases are making them increasingly significant. Super capacitors, fuel cells, and batteries are examples of storage mechanisms for energy that are used to store power, which is used as energy for electric vehicles (EVs) and powers their electric motor. Lead-acid and nickel metal hydride batteries were originally utilized in automobiles. Li-ion batteries (LIBs) have risen to the top of the market for usage in electric vehicles (EVs) thanks to recent improvements. State of charge (SOC) estimate has grown in importance inside the battery management unit (BMS) and has contributed to the advancement of electric car technology. The added benefit is that it gives users access to precise SOC measurements through real-time battery monitoring. This lowers the danger of overvoltage cells by extracting correct SOC measurements from certain battery charging and discharge procedures. Many techniques for estimating state of charge (SOC) rely on the open circuit voltage (OCV) gradient. This paper examines the impact of a voltage reduction in high-power lithium-ion batteries for 0% to 100% SOC at various degrees and c-rates. The outcome demonstrates that the voltage reduction is greater at higher C rates than it is at lower C rates, and this is also true at higher temperatures.

KEYWORDS: EV, SOC. C Rate

I. INTRODUCTION

An automobile powered by electricity is one that is propelled by any number of propulsion motors, which are electric motors utilised to propel vehicles such as locomotives, lifts, etc. merely may electric automobiles be found on roads and in trains, but they can also be found in ground and submerged vehicles, electric aeroplanes, and electric spaceships. EVs are frequently referred to as electric cars, but because of a significant surge in popularity in the twenty-first century brought about by technological advancements, all of them collectively are referred to as E-mobility [1-3]. Because they use fewer resources to go the identical travel distance, minimize contaminants in the air, and stop contributing to climate change because of their pollutants, electric vehicles, also known as EVs, are becoming increasingly prevalent.

The structure of the several cell types of batteries that make up each battery component in the electric vehicle battery subsystem varies according to the demands. The aim of the electronic transportation battery evaluation is not only the battery's reliability and endurance, but also its response to various ambient conditions. Another way to look at EV battery protection is to separate it into four categories: practical, thermal/environmental, physical, and electrical reliability. Electrical security covers a variety of topics, such as forced expulsion, overcharging, nail permeation, and short

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trip.

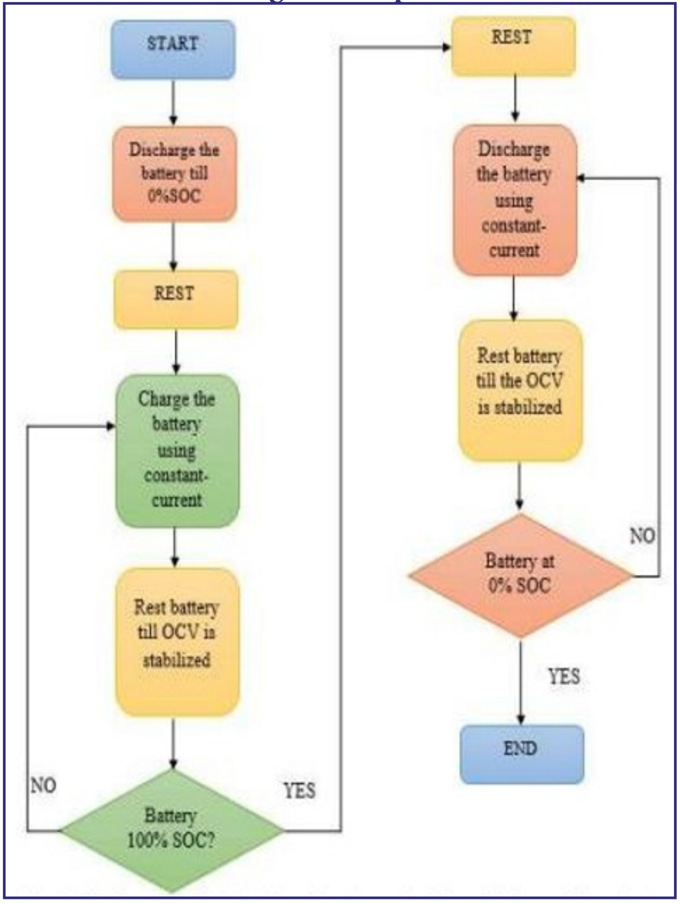
Included in physical security are breakdown, tremors, fall, and trauma. Hazardous protection, moisture, elevation modelling, heat cycling, and thermal trauma cycling are all included in environmental security. Leaking, air circulation, dissection, combustion, and possibly detonation are among the possible risks. Thus, it is crucial to conduct tests on the safety of EV batteries. The effectiveness of electric automobiles is mostly dependent upon the battery pack, which essentially determines the extent of range. Consequently, selecting the right battery innovation and using it effectively are crucial. Li-ion the field of chemistry has become the preferred battery material of nowadays because of its high capacity for energy, high power assessment, and efficient charging and discharging in pulsating circulation of energy devices [4-5].

Typically, an extensive amount of cells are linked in either parallel or series, according to the purpose, to create a battery thread that has the appropriate voltage and capacity. Lithium-ion batteries that have various chemistries are particularly vulnerable to extensive drain and overcharging, that can harm the power source, reduce its lifespan, and potentially put it in danger. The implementation of an appropriate Battery Control System (BMS) is necessary to ensure that every battery unit remains throughout its secure and dependable operational parameters. Apart from the battery protection's main purpose, a BMS ought to determine the battery condition to estimate how much power will really be able to reach the demand. [6–8].

II. OCV-SOC ESTIMATION

High-powered Li-ion batteries (LIBs) have had their charge or discharge activity examined at various state of charge (SOC) levels and classified into five categories: look-up database approach, coulombs counting approach, model-based estimate approach, data-driven evaluation approach, and hybrid approach. The properties of the OCV-SOC slope might be investigated through a laboratory test and the collection of massive amounts of statistical information in the manner of a lookup table approach. The instantaneous tracing of the link among the SOC and exterior factors, like the open circuit, is demonstrated by the look-up table approach. Using this approach, the association is tabulated by conducting extensive do a test in the lab to describe the battery's functionality [9–10]. The OCV-SOC estimate structure using the look-up table approach displays several parameters such as impedance and voltage (OCV) is provided below.

Fig. 1: The flow chart of OCV-SOC estimation method through look up table method

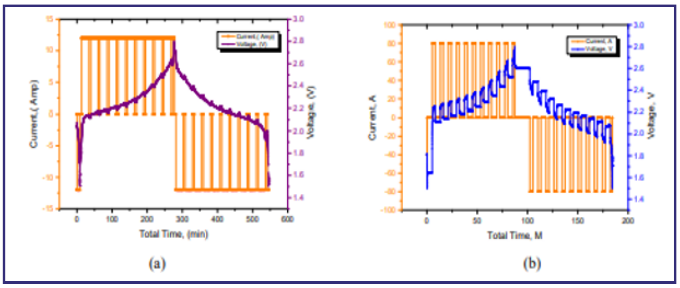


In this study, an annular Li-ion NMC battery pack with a maximum rating of 40Ah and a recommended voltage of 2.3V is employed. A battery-operated testing cycler had been attached to the NMC battery pack. The voltage and current wires are utilized to provide the cell with the appropriate current and voltage corresponding on the study's demands for current and voltage. The purpose of the battery cell is to evaluate crucial factors such as amp-hour, voltage, current, temperature, and power. Both software and hardware parts make up two completely distinct parts of the designed testing desk concept. An LCN Bitrode component part is included in the physical component, and Visual LCN application is used to provide parameters for control. We employ a variety of charging or discharging stages for charge, discharge, and idle stages in the software portion of the configuration so that we can determine the precise OCV. A thermal sensor is positioned at the LIB's interface to monitor the exterior temperature of the battery cell at various C-rates, 40 °C, and the surrounding atmosphere throughout charge and discharge. Firstly, each cell is allowed to rest until the research procedure is started. The battery is

charged and discharged using an electrical pulse at two distinct levels of current (0.3 C-rate and 2 C-rate) during the procedure. Throughout the course of the study, the exterior temperature of the lithium-ion cell may be monitored. At 40 °C, same study was likewise carried out in a secure heat compartment. Continuous constant current/voltage, or CC-CV, was used for charging the battery. The battery cell had been charged until the voltage reached the maximum permissible level of 2.8 V (the minimum limit is considered as 1.5V, and because the battery's typical voltage is 2.3V, 10% additional must be taken into consideration to calculate the higher limit). Prior to the start of the studies, the cells were at idle. To ascertain the OCV's heat dependency, the research study was run at both room temperature & 40 °C.

At first, a cell is brought to 0% SOC by fully discharging the LIB. Constant current (CC) technique is utilized for charging LIB each 10% of SOC once it has been completely depleted to 0% SOC. The LIB is held at idle for a few minutes once reaching 100% SOC. It is then drained at a constant current (CC) then left at idle for a predetermined amount period to allow the OCV to settle down. This process is repeated until the lithium-ion battery is completely depleted. The SOC stage may be found by determining the present OCV of LIB after the query table has been constructed. The relationship among the OCV and SOC is then mapped after that. To comprehend the open-circuit voltage (V) at different SOCs, additional voltage reduction (ΔV) is being studied at all states of charging throughout charging and discharging. The spectrum of both charging and discharging at 0.3C and 2C rates at room temperature and 40°C is provided below:

Fig. 2: Charge and discharge plot for (a) 0.3C-rate and (b) 2C rate at ambient temperature and at 40^{0}C



The voltage, current, charging, discharging, and idle time period are displayed on the horizontal axis of the accompanying figure, which is represented by the Y-axis. Testing of the lithium-ion cell was conducted using a constant current (CC) charging methodology at a 0.3C rate. For every SOC & electrical current pulse, the battery gets charged and released at 12A of current, having a 5-minute idle interval in between. The voltage indicates that the battery has 100% SOC once it hits the top threshold of 2.8V. Once the cell hits 2.8V, it is drained using 12A of electrical current until the voltage drops to 1.5V, or 0% SOC. The current and voltage monitoring times were recorded for every moment of the study.

III. RESULTS & DISCUSSION

The OCV is collected at the exterior temperature throughout the process of charging and discharging operation at an interval of 0.3C for each 10% of SOC. Each 10% of SOC causes a constant rise in the OCV. The OCV increase started out between 0.02 and 0.03 for each 10% step, while in the final few phases, it stayed between 0.08 and 0.10. Table 1 displays the OCV readings at various SOCs and suggests the battery's voltage approaches 2.60V, or about its entire capacity with 100% SOC. The procedure for discharging is indicated by a negative symbol next to current numbers in Table 1. The whole procedure of charging and discharging takes about 8.66 hours.

Table 1. OCV during charge and discharge cycles at 0.3C-rate for every 10% SOC at Ambient temperature

Charging Cycle			Discharging Cycle		
SOC (%)	Current (I)	Voltage (V)	SOC (%)	Current (I)	Voltage (V)
0	12	1.500	100	-12	2.473
10	12	2.133	90	-12	2.376
20	12	2.160	80	-12	2.299
30	12	2.183	70	-12	2.241
40	12	2.207	60	-12	2.200
50	12	2.234	50	-12	2.171
60	12	2.272	40	-12	2.146
70	12	2.328	30	-12	2.118
80	12	2.402	20	-12	2.083
90	12	2.494	10	-12	1.999
100	12	2.608	0	-12	1.500

The OCV readings throughout the charging and discharging phases at 0.3C-rate for each 10% SOC for 40 °C are displayed in Table 2. Additionally, the pattern is comparable to trials conducted at a room temperature.

Table 2. OCV during charge and discharge cycles at 0.3C-rate for every 10% SOC at 40 °C

Charging Cycle			Discharging Cycle		
SOC (%)	Current (I)	Voltage (V)	SOC (%)	Current (I)	Voltage (V)
0	12	1.500	100	-12	2.463
10	12	1.681	90	-12	2.368
20	12	2.128	80	-12	2.290
30	12	2.154	70	-12	2.232
40	12	2.178	60	-12	2.191
50	12	2.200	50	-12	2.162
60	12	2.227	40	-12	2.136
70	12	2.265	30	-12	2.109
80	12	2.394	20	-12	2.075
90	12	2.484	10	-12	1.960
100	12	2.601	0	-12	1.500

When the battery is charged and released at an intensity of 2C for each 10% of SOC, the open circuit voltage (OCV) is measured under room temperature conditions. Each 10% of SOC results in a constant rise of the OCV. In contrast with the latter phases, the OCV increase was larger at first. Table 3 displays the OCV at various SOCs and suggests the pack of batteries approaches its maximum capacity of 2.52V at 100% SOC. Table 3's current readings with a negative value denote the discharge phase. Approximately 2.66 hours are needed to go through the entire process of charging and discharging. The procedure of charged and draining is quick.

Table 3. OCV during charge and discharge cycles at 2C-rate for every 10% SOC at Ambient temperature

Charging Cycle			Discharging Cycle		
SOC (%)	Current (I)	Voltage (V)	SOC (%)	Current (I)	Voltage (V)
0	80	1.500	100	-80	2.391
10	80	1.987	90	-80	2.303
20	80	2.209	80	-80	2.230
30	80	2.233	70	-80	2.175
40	80	2.254	60	-80	2.135
50	80	2.275	50	-80	2.106
60	80	2.299	40	-80	2.081
70	80	2.330	30	-80	2.056
80	80	2.377	20	-80	2.023
90	80	2.442	10	-80	1.970
100	80	2.521	0	-80	1.500

The OCV readings throughout the charging and discharging processes for 2 C-rate with each 10%

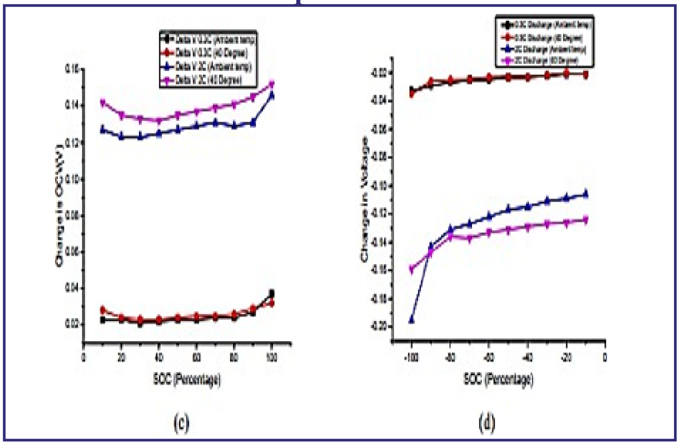
SOC for 40 °C are displayed in Table 4. Additionally, the pattern is comparable to trials conducted at room temperature.

Table 4. OCV during charge and discharge cycles at 2C-rate for every 10% SOC at 40 °C

Charging Cycle			Discharging Cycle		
SOC (%)	Current (I)	Voltage (V)	SOC (%)	Current (I)	Voltage (V)
0	80	1.500	100	-80	2.289
10	80	1.813	90	-80	2.217
20	80	2.222	80	-80	2.161
30	80	2.248	70	-80	2.122
40	80	2.272	60	-80	2.093
50	80	2.294	50	-80	2.093
60	80	2.318	40	-80	2.069
70	80	2.349	30	-80	2.043
80	80	2.393	20	-80	2.013
90	80	2.455	10	-80	1.969
100	80	2.532	0	-80	1.500

Plotting and analysis of the decrease in voltage (ΔV) at room temperature & 40 °C, in addition to with 0.3 and 2 C rates throughout the charging and discharging processes, have been done for every level of charging. The outcome is displayed in Figs. 3(a) and 3(b).

Fig. 3: Voltage drop (ΔV) vs SOC for (a) charge and (b) discharge cycles for 0.3 C and 2 C rate and at ambient temperature and at 40° C.



The figures make it evident that, in comparison to 2C rate for both charging and discharging processes, the amount of voltage loss at 0.3 C pace is extremely small. The temperature influence on the electrical voltage loss in each of the 0.3C rate & 2C rate charging and discharging settings results in a modest rise. Figs. 3(c) & 3(d) show the combination of waveforms of the electrical voltage reduction at 0.3C pace and 2C pace at room temperature & 40 °C.

At either room temperature and 40 °C, the voltage that will decrease throughout the charging process at an average rate of 0.3C falls between 0.02 and 0.03 V. In contrast, the electrical voltage reduction at a 2C rate ranges from 0.12 to 0.15. When comparing 40 °C to the surrounding temperature, there can be a noticeable difference in the voltage decline (approximate 0.11).

Fig. 3:- Combined graph for voltage drop (ΔV) vs SOC for (c) charge and (d) discharge cycles for 0.3 C and 2 C rate and at ambient temperature and at 40 C The decline in voltage at 0.3 C speed throughout the discharge procedure cycle ranges from 0.02 to 0.03 V regardless of room temperature and 40 °C. In contrast, the voltage reduction at a 2 C rate ranges from 0.10 to 0.16. When comparing 40 °C with the surrounding temperature, there's a noticeable difference in voltage loss (approximate 0.11).

IV. CONCLUSION

The investigation of the OCV-SOC properties of high-powered LIB utilizing NMC chemistry with various temperature influences is the main goal of the current work. The outcome demonstrates that a single may forecast the remaining power of packs for a specific voltage threshold utilizing the OCV-SOC attributes trajectory, which also depends on the ambient temperature. We looked at the link between the SOC and OCV of lithium-ion battery cells at various temperatures and C-rates. Both the charging and discharge speed improve with increasing C-rate.

It is regarded as sluggish charging and sluggish discharging beneath 1C and quick charged and fast draining over 1C. While discharging at various C-rates, the more extreme C-rate offers a lesser OCV for each 10% of SOC, while the high C-rate has much greater OCV readings overall. Increased ambient temperature results in a lower discharging cut off potential for the battery's cells, as seen by a complete downhill change in the OCV vs. SOC features graph. Conversely, decreasing ambient temperature raises the lithium-ion battery's discharging threshold voltage, which prevents a large amount of power from the battery from being discharged during the procedure of discharging. To comprehend the open circuit voltage for various SOCs, a voltage reduction (ΔV) was calculated and studied for every type of charging throughout charging and discharging.

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