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DEPARTMENT OF MECHANICAL ENGINEERING

Project Report for Project Phase 1
(18MEP79)

on

Thermal Characterization of Sodium Ion battery-Experimental Study

Submitted by

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Certificate

This is to certify that the project entitled **"Thermal Management of Sodium Ion Battery" Phase 1 (18MEP79)** report submitted by **Pratham Yadav Borkar (1NT20ME053), Dushyanth Chilukuri (1NT20ME022),** bonafide students of **Nitte Meenakshi Institute of Technology**, **Bengaluru** in partial fulfilment for the award of B.E Degree in **Mechanical Engineering** of the **Visvesvaraya Technological University,** Belagavi, during the academic year **2023-24** is an authentic work carried out by them under my supervision and guidance**.** Itis certified that all corrections/suggestions indicated by me have been incorporated in the report submitted to the department library. The project work report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said degree.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

With ever growing population, the demand for transportation increases, which can lead to increased use of fossil fuels and greater environmental impact. In areas with high population density, such as cities, the need to improve air quality and reduce traffic congestion may be greater, making the transition to EVs more pressing. Additionally, in countries with large populations, such as China and India, the demand for energy is likely to increase, making the need to reduce dependence on fossil fuels more important. On the other hand, in countries with lower population densities, the need to switch to EVs may be less pressing. Overall, population can be a factor that can influence the need to switch to EVs, but it is not the only one.

Lithium-ion batteries are widely used as the primary source of power in electric vehicles (EVs) because of their high energy density, long cycle life, and relatively low cost. The high energy density of lithium-ion batteries allows for a smaller and lighter battery pack, which in turn, allows for a more aerodynamic and lightweight vehicle. The long cycle life of lithium-ion batteries means that they can be charged and discharged many times before losing capacity, which is important for EVs, as it means that the battery can last for a long time. Additionally, lithium-ion batteries are relatively low cost compared to other battery technologies, which makes them more cost-effective for use in EVs. Overall, lithium-ion batteries offer the best combination of performance, cost, and safety, making them the preferred choice for use in EVs.

Sodium is being researched as a potential alternative to lithium in rechargeable batteries, particularly for use in electric vehicles (EVs), because of its abundance and low cost. Sodium is much more abundant than lithium, making it a more sustainable and cost-effective material for use in batteries. Sodium-ion batteries have the same working principle as lithium-ion batteries, but the use of sodium instead of lithium can make the batteries cheaper to produce.

1.2 Sodium Ion Battery

A sodium ion battery is a type of rechargeable battery that uses sodium ions as the charge carrier instead of lithium ions, which are used in traditional lithium-ion batteries. Sodium ion batteries are being researched as a potential alternative to lithium-ion batteries due to the abundance and low cost of sodium compared to lithium. However, they currently have lower energy densities and shorter lifetimes than lithium-ion batteries.

The operating principle of a sodium-ion battery is similar to that of a lithium-ion battery. Both types of batteries use a cathode and an anode, with an electrolyte in between. During discharge, sodium ions are extracted from the cathode and travel through the electrolyte to the anode, where they are stored. During charging, the process is reversed, and the ions travel back to the cathode. The main difference between the two types of batteries is the type of materials used in the cathode, anode, and electrolyte. In a sodium-ion battery, the cathode is typically made of a sodium-rich material, while the anode is made of carbon. The electrolyte is typically a liquid or gel that contains sodium ions.

Sodium-ion batteries, like all batteries, generate heat during operation. This heat is generated because of the chemical reactions that take place within the battery, such as the movement of ions between the electrodes. The heat generation in sodium-ion batteries can be affected by several factors, including the rate of charge and discharge, the temperature of the battery, and the state of the battery's electrodes.

One of the challenges of sodium-ion batteries is that they tend to generate more heat than lithium-ion batteries, because of the larger ionic radius of sodium ions. This can lead to thermal runaway, a phenomenon where the temperature of the battery increases uncontrollably, which can cause damage to the battery and even lead to a fire.

Thus arises a need for thermal management system for a Sodium ion battery, to ensure it remains functional with good efficiency.

Figure 1: Cylindrical sodium ion battery

1.3 Thermal Management:

Thermal management in batteries is the process of controlling and maintaining the temperature of the battery cells within a safe operating range to ensure the performance, safety and longevity of the battery. Batteries, generate heat during operation, and if the temperature becomes too high, it can lead to thermal runaway, a phenomenon where the temperature of the battery increases uncontrollably, which can cause damage to the battery and even lead to a fire.

There are several methods for thermal management in batteries:

Passive methods: This includes the use of thermal insulation materials, such as thermal tapes, to reduce heat loss and increase thermal conductivity.

Active methods: This includes the use of cooling systems, such as air or liquid cooling, to remove heat from the battery and maintain a safe operating temperature.

Combination of both: This method is a combination of passive and active thermal management, where passive methods such as thermal insulation materials are used in conjunction with active methods such as cooling systems to improve thermal management.

Battery Management System (BMS): A BMS can monitor the battery temperature and adjust the charging and discharging parameters accordingly to prevent the battery from getting too hot. Thermal management is a critical aspect of batteries and different methods can be used depending on the specific requirements of the application and the type of battery used.

CHAPTER 2
LITERATURE REVIEW

2.1 Thermal Management

- Rajesh Akula, C. Balaji, 2022, has discussed in his paper “Thermal management of 18650 Li-ion battery using novel fins–PCM–EG composite heat sinks”.

The present study introduces a novel fin–Phase Change Material (PCM)–Expanded Graphite (EG) composite for better thermal management of a Panasonic NCR18650BD battery at discharge rates higher than its maximum discharge limit 2C. Fins and EG are augmented with PCM to enhance its effective thermal conductivity.

- Chen, K., Hou, J., Song, M., Wang, S., Wu, W., & Zhang, Y. 2019 demonstrated in his paper “Design of battery thermal management system based on phase change material and heat pipe”.

The performance of battery thermal management system (BTMS) with phase change material (PCM) and heat pipe (HP) is studied. The performance of the BTMS is compared to that of the one with solely HP, find that PCM can effectively reduce the temperature difference in battery pack.

- Rajesh Akula & Chakravarthy Balaji. 2021 demonstrated in his paper “Effect of PCM fill ratio and heat sink orientation on the thermal management of transient power spikes in electronics”.

To investigate the usefulness of Phase Change Material based heat sinks in power surge operations. Most of the electronic equipment draws high power either during the starting of operation or when they start working on full load conditions.

- Tran, M.-K., Cunanan, C., Panchal, S., Fraser, R., Fowler, M. 2021 demonstrated in his paper “Investigation of Individual Cells Replacement Concept in Lithium-Ion Battery Packs with Analysis on Economic Feasibility and Pack Design Requirements”.

This paper used a simulation framework, based on a cell voltage model and a degradation model, to study the feasibility and benefits of the cell replacement concept. It was found that the cell replacement method can increase the total number of cycles of the battery packs, effectively prolonging the lifespan of the packs.

- Jingwen Wenga, Dongxu Ouyanga, Xiaoqing Yangb, Mingyi Chenc, Guoqing Zhangb, Jian Wang, 2020, has discussed in his paper “Optimization of the internal fin in a phase-change-material module for battery thermal management”.

An optimized PCM module combining various fins is designed and tested for its thermal performance, where a greater balance between the heat absorption and heat dissipation is obtained with lower maximum battery temperature and smaller temperature range.

- Kai Chen, Yiming Chen, Mengxuan Song, Shuangfeng Wang, 2022, has discussed in his paper “Multi-parameter structure design of parallel mini-channel cold plate for battery thermal management”.

Battery pack is cooled by the parallel mini-channel cold plate. The edge width and convergence channel width of the three systems are designed & among the three the performance of the symmetrical PMCPs I & Z is better than symmetrical PMCP U. It is observed that the cooling performance of a parallel mini-channel cold plate can be significantly improved.

- Kudakwashe Chayambuka, Ming Jiang, Grietus Mulder, DmitriL. Danilov, Peter H.L. Notten, 2021, has discussed in his paper “Physics-based modeling of sodium-ion batteries part I: Experimental parameter determination.”

This proclamation is based on recent technological trends and the outstanding performance of the state-of-the-art prototype 18650 and pouch cells. In this contribution, experimental characterizations of SIB electrode materials based on Na3V2(PO4)2F3 (NVPF) cathode and hard carbon (HC) anode are presented. electrodes. Based on the analyses of Na//NVPF and Na//HC half-cells, diffusion mass transport limitations and Ohmic losses are identified for both electrodes.

- Kudakwashe Chayambuka, Ming Jiang, Grietus Mulder, DmitriL. Danilov, Peter H.L. Notten, 2021, has discussed in his paper, “Physics-based modeling of sodium-ion batteries part II. Model and validation”.

Herein, a physics- based, pseudo-two-dimensional (P2D) model is introduced for SIBs. The P2D SIB model is based on Na3V2(PO4)2F3 (NVPF) and hard carbon (HC) as positive and negative electrodes, respectively. It is shown that the model is highly accurate in predicting the discharge profiles of full cell HC//NVPF SIBs. In addition, internal battery states, such as the individual electrode potentials and concentrations, can be obtained from the model at applied currents.

- Kudakwashe Chayambuka, Ming Jiang, Grietus Mulder, DmitriL. Danilov, Peter H.L. Notten, 2021, has discussed in his paper, “Physics-based modeling of sodium-ion batteries part II. Model and validation”.

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CHAPTER 3

METHODOLOGY

3.1 Battery modelling

Battery modeling is the process of creating mathematical models that simulate the behavior of a battery under different operating conditions. These models can be used to predict the performance, lifetime, and safety of a battery, as well as to optimize the design of the battery and the charging and discharging algorithms.

The cell investigated in this study is Na-ion cylinder cell cooled by a mini-channel cold plate. Figure 3.1 depicts the geometry and mesh of a single battery cell. Ansys software is used to create a high-quality structured mesh for modelling. The cell geometry parameters are listed in Table 3.1. The high-energy Na-ion cell's nominal voltage and capacity are 3.3 V and 20 Ah, respectively.

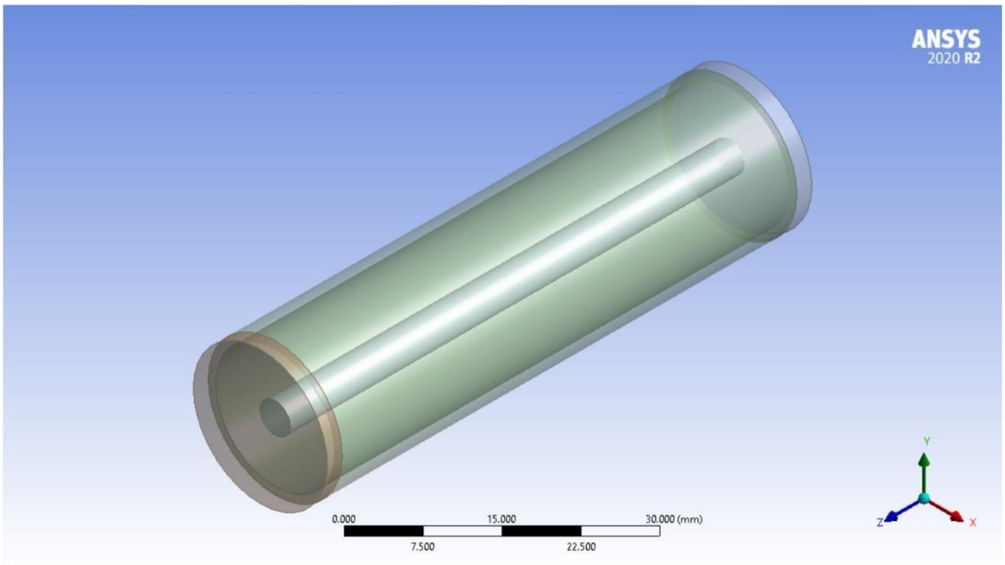

Figure 3. 1: Geometry and mesh of single Na-ion cylinder cell

Sl.No.	Characterisitic	Value
1	Length	65mm
2	Diameter	18mm
3	Normal Voltage	3.6V
4	Cut Off Voltage	2.5V

Na-ion battery modeling is hard due to its multi-scale nature. The battery scale transport equations must be solved to predict the temperature using the thermal management method. The differential equations are discretized in the CFD domain at battery cell scale to solve the battery thermal and electrical fields. The equations will depict the governing of the current flux at positive electrode and negative electrode respectively.

3.2 Battery Characterization Sub model

The Equivalent Circuit Mode (ECM) model, the Newman, Tiedemann, Gu, and Kim (NTGK) model, and the physics-based model are three of the most used techniques for developing a thermal model. For Na-ion battery modelling using ECM, the Thevenin-based electrical model is utilized. Thevenin-based ECM models are particularly popular and widely utilized due to their simplicity and lack of impedance measuring instrument requirements. Pulse discharge (PD) experiments on a battery in a laboratory environment are used to determine the parameters of the Thevenin equivalent circuit model. A Thevenin equivalent circuit is used to mimic the voltage response to current excitation, which is represented in Figure 3.2, where sQ is the SOC, uoc is the OCV, ub is the terminal voltage, ib is the terminal current, R0 is the ohmic resistance, R1 ,...,Rn are the dynamic resistances, and C1 ,...,Cn are the corresponding dynamic capacitances. All resistances and capacitances are functions of the SOC, temperature, current direction, and cycle life.

(a) (b)

Figure 3. 3: a) NEWARE, BTS-4000 battery charge discharge cycle tester b) Thermocouples attached on either side of the battery connected to Data Acquisition center to record temperatures during battery testing

Cylindrical cell and packing material

The cylindrical cell continues to be one of the most widely used packaging styles for primary and secondary batteries. The advantages to using this cell format are manufacturing convenience and mechanical stability. Indeed, this cell design is easier to manufacture and with a sealed can exteriorly withstand high internal pressures. The cylindrical cell package is also equipped with a resealable vent to release pressure under excessive charge. Applications that predominantly use cylindrical cells include wireless communications, biomedical instruments, power tools and similar applications that do not demand an ultra-compact battery size.

Owing to the popularity of the cylindrical cell geometry, cylindrical cell packaging material is the most commonly available packaging for lithium-ion batteries today.

Cell packing configuration.

Parallel then Series

This is the approach used in most passenger car electric vehicles and smaller battery pack designs. All of the cells working in parallel are joined together in groups and then these are joined in series.

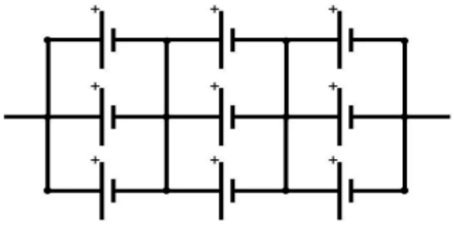

Figure 3. 5: Thevenin equivalent electrical model of a Na-ion battery

Balancing Currents

In the case of the parallel and then series arrangement there will be balancing currents flowing within the parallel groups of cells. These occur due to small differences in the cells, cooling, connection resistance and how they age. These currents will be there rebalancing the cells.

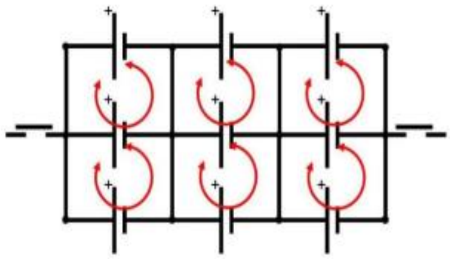

Figure 3. 5: Thevenin equivalent electrical model of a Na-ion battery

Battery Management System

One BMS can manage the battery pack as a whole.

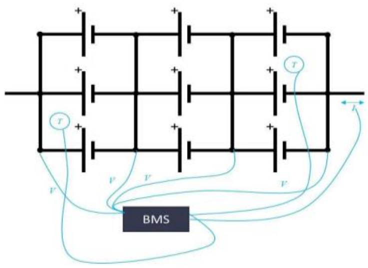

Figure 3. 5: Thevenin equivalent electrical model of a Na-ion battery

Series than Parallel

This approach gives more flexibility for very large packs. The cells are wired together in series to get to the full system voltage, these series strings are then connected in parallel.

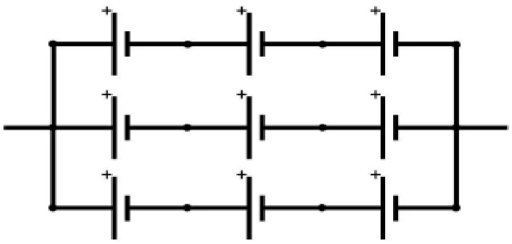

Figure 3. 5: Thevenin equivalent electrical model of a Na-ion battery

Balancing Currents

The current flows between the series strings will flow when the strings are brough together in parallel. Hence it is important to measure the voltage of each string and set limits on the differences. The difficulty occurs if the differences are too great. Then a decision must be made as to whether you isolate parts, or you charge/discharge to bring them into alignment. You could use a pre-charge resistor, but this might take a long time to align the strings.

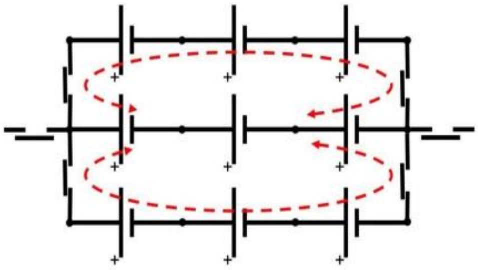

Figure 3. 5: Thevenin equivalent electrical model of a Na-ion battery

Battery Management System

One BMS is required to manage each series string, each string is a battery pack in its own right. A master BMS then has to sit over the top managing the total system and having to make decisions on how these are connected together and under what conditions.

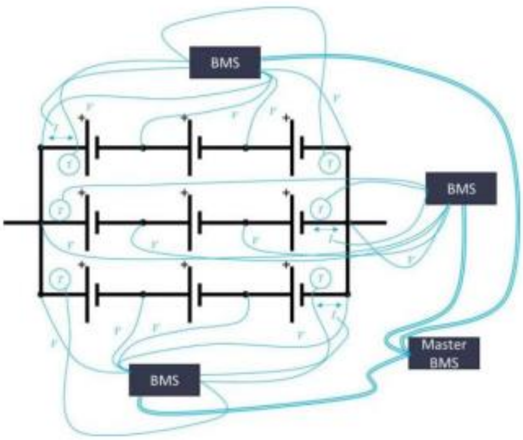

Figure 3. 5: Thevenin equivalent electrical model of a Na-ion battery

3.3 Equivalent Circuit Topology

The number of RC branches in the circuit topology is chosen optimally to mimic the dynamic behavior of the battery during a pulse discharge test. The battery pulse discharge test was carried out in the laboratory using an experimental setup. The setup consists of Na-ion cylinder cell, thermocouples, battery charge discharge cycle tester (NEWARE, BTS-4000), Key sight Data Acquisition system as shown in Figure 3.3. The battery tester was used to charge the battery cell using the constant current and constant voltage method. The Na-ion cell is charged with 1C rate till it reaches 3.6 V (cut-off voltage) and charged with constant voltage till current becomes zero. Once the cell is charged completely, the cell was pulse discharged with a 20 A pulse current until the minimum cut-off voltage was reached. Every pulse discharge phase is 360 seconds long, with a one-hour rest interval in between.

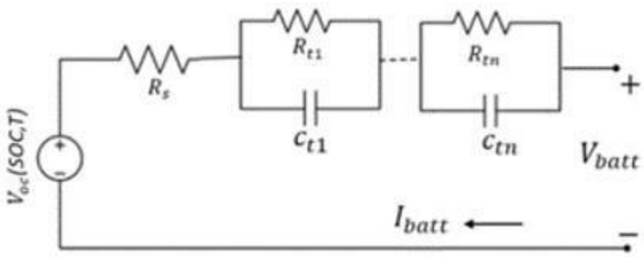

Figure 3. 5: Thevenin equivalent electrical model of a Na-ion battery

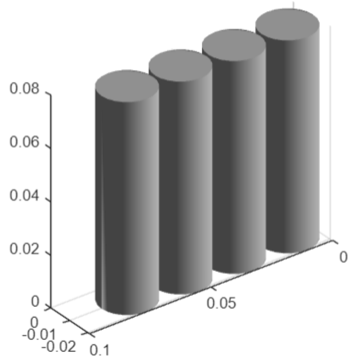

Figure 3.6 Cell in Series

The terminal voltage of the cell is considered stable enough to estimate the OCV of the cell after each 1-hour rest period. The SOC of the cell remains constant during the rest period. Experimental plot of pulse discharge test is shown in Figure 3.4. During the SOC range of 20-100 percent, a 10% SOC declination was set as a target in each of the pulse discharge cycles and a 5% SOC declination was established as a target during the SOC range of 0-20 percent to capture the extremely dynamic behavior of the cell.

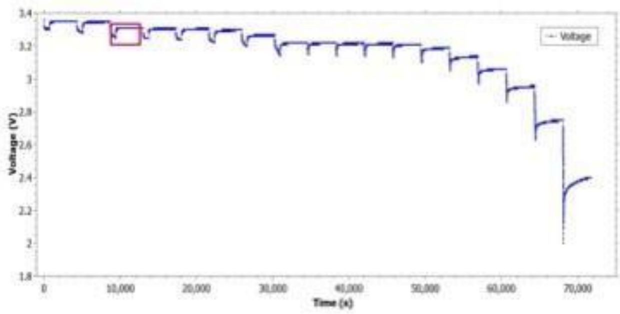

Figure 3. 7: Illustration of Pulse Discharge Experiment for battery

For determining the optimal number of branches, the relaxation period for one pulse is taken and fitted against N-exponential curves. The best fit curve is chosen as the optimal value for the number of ranches as shown in the Figure 3.5. The final proposed model uses 2 RC branches where the first RC branch overs fast transients, and the second RC circuit covers slow

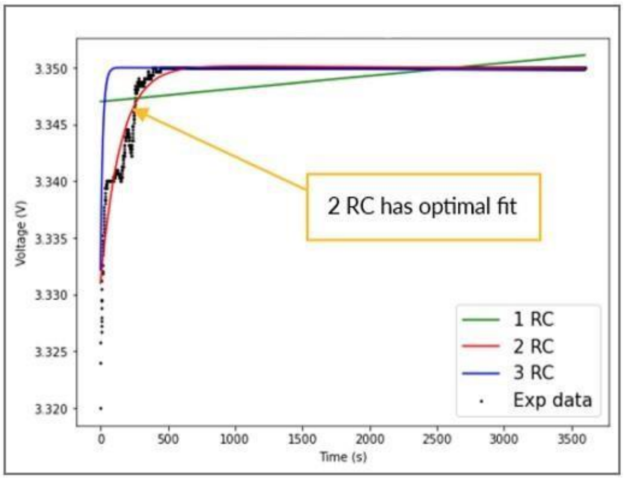

Figure 3. 8: Relaxation period of pulse discharge curve fitted against N-exponential curves

3.4 Parameter Extraction

The parameters identification methods are based on analysis of the voltage relaxation characteristics during the rest time of pulse discharge test. The pulse beginning and ending times are first determined, and the data is then divided into partitions. The number of partitions is decided by the number of RC branches in the circuit. The time window split-up is done according to the following time instants as shown in Figure 3.6 where:

$t_{c\ pe}$ = time instant at which the discharge pulse terminates, and the current begins to fall

t_0 = time instant at which the current has returned to zero

t_{12} = time instant at which first window ends

t_{21} = time instant at which second window starts

t_{22} = time instant at which second window ends

t_{end} = time instant at which the rest period ends

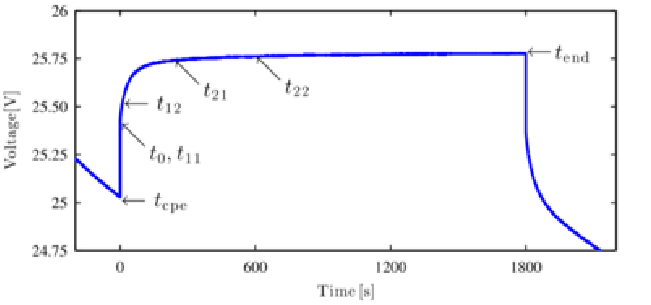

Figure 3. 8: Illustration of time window on pulse discharge test

The time gap between the two windows must be long enough to ensure the voltage of the shorter time constant branch should fall very close to zero. The time instant t_{22} should be at least three times the shorter time constant to ensure the voltage of the shorter time-constant branch has dropped below 5% of its initial value.

The voltage characterization process is used to calculate the values of resistances and capacitances. The SOC of the cell is assumed to be constant during the rest cycle, hence the parameters are determined during the cell's rest period for each relaxation period. The model parameters were fitted using nonlinear curve fit function which uses non-linear squares method using Levenberg–Marquardt algorithm.

3.5 Thermal Management

Based on the heat generated under simulation at different C-rates, a thermal management system can be developed to control and maintain the temperature of the battery cells within a safe operating range. During the simulation, the heat generated by the battery under different C-rates can be measured and analyzed, this data can be used to estimate the heat dissipation requirements for the battery under different operating conditions.

This information can be used to develop a thermal management system that can actively control the temperature of the battery cells and maintain them within a safe operating range, regardless of the C-rate at which the battery is being charged or discharged. This can be done by using active cooling methods, such as air or liquid cooling, or by using a combination of passive and active thermal management methods.

A thermal management system can be an important aspect of battery design and operation, as it can help to prevent thermal runaway, a phenomenon were the temperature of the battery increases uncontrollably, which can cause damage to the battery and even lead to a fire. Additionally, a well-designed thermal management system can help to improve the performance, safety and longevity of the battery.

The battery's heat is controlled using a combination of paraffin wax and expanded graphite. The fins on the battery help to increase the surface area that is in contact with the heat transfer material (PCM), which helps to dissipate the heat away from the battery.

CHAPTER 4

RESULTS AND DISCUSSION

[1] Packing of Sodium Ion Batteries of 4 cell and 5 cell in parallel and series configuration.

[2] Heat generation test in battery pack.

[3] A Pulse discharge test of cylindrical Sodium ion battery was carried out and parameters to generate the ECM model of the battery was obtained.

REFERENCES

[1] Rajesh Akula, C. Balaji, 2022, has discussed in his paper “Thermal managementof 18650 Li-ion battery using novel fins–PCM–EG composite heat sinks”.

[2] Chen, K., Hou, J., Song, M., Wang, S., Wu, W., & Zhang, Y. 2019 demonstratedin his paper “Design of battery thermal management system based on phase change material and heat pipe”.

[3] Rajesh Akula & Chakravarthy Balaji. 2021 demonstrated in his paper “ Effect of PCM fill ratio and heat sink orientation on the thermal management of transient power spikes in electronics”.

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