LITHIUM-ION CELL BALANCING USING BUCK-BOOST CONVERTER

MUHAMMAD HAZWAN BIN HASHIM

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Faculty of Engineering
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DEDICATION

This project report is dedicated to my adored wife, Fairus Niza Binti Ab Majid, who encouraged and inspired me endlessly in my journey to pursue my studies in this field. Without her support and motivation, I would not have completed this work.

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ABSTRACT

The lithium-ion battery has gained considerable attention in Electric Vehicle sectors compared to the conventional lead-acid battery. It became commercially popular and used due to its salient characteristics such as high terminal voltage, energy density and power density of a single cell. However, if there is no proper power regulation during the process of both charging and discharging, the life span of the batteries will significantly decrease and leads to undesirable results such as fire or explosion at times which become a major drawback of lithium-ion (Li-ion) batteries. Proper power regulation is essentials and battery management system (BMS) are employed to circumvent these problems. SOC estimation, cell balancing, and thermal management are the common subsystems of battery management system (BMS). These subsystems are required to perform in real time and under conditions of rapid charging and discharged. Cell balancing is very crucial subsystem of the BMS which will efficiently prolong the battery life span. Thus, not only does the cell balancing method cover the task of protecting the cells, it also involves the task of equalizing charges between the cells. In electronic devices, the most common cell protection mechanism used is interruption of the charging and discharging process of the battery in order to prevent the battery from reaching its maximum and minimum permissible voltage. The charge imbalance among batteries occurs in the form of unequal voltages along the series connected batteries. The two major categories of cell balancing methodologies are active methods and passive methods. In this project, both categories of cell balancing will be studied extensively, and an efficient and suitable converter based active method is proposed and simulated using MATLAB Simulink.

ABSTRAK

Bateri lithium-ion telah mendapat perhatian besar di sektor Kenderaan Elektrik berbanding dengan bateri asid plumbum konvensional. Ia menjadi terkenal secara komersial dan digunakan kerana ciri khasnya seperti voltan terminal tinggi, ketumpatan tenaga dan ketumpatan kuasa satu sel. Walau bagaimanapun, jika tidak ada pengaturan kuasa yang baik dan bersesuaian ketika proses caj dan discaj sel bateri, jangka hayat bateri akan berkurang dengan ketara dan membawa kepada hasil yang tidak diingini seperti kebakaran atau letupan dan ia merupakan salah satu kelemahan utama bateri lithium-ion (Li-ion). Pengaturan kuasa yang betul adalah penting dan sistem pengurusan bateri (BMS) digunakan untuk mengatasi masalah ini. Anggaran SOC, pengimbangan sel, dan pengurusan termal adalah subsistem umum sistem pengurusan bateri (BMS). Subsistem ini diperlukan untuk berfungsi dalam masa sebenar dan dalam keadaan pengecasan pantas dan lengkap. Pengimbangan sel adalah subsistem BMS yang sangat penting yang akan memanjangkan jangka hayat bateri dengan cekap. Oleh itu, bukan sahaja kaedah pengimbangan sel meliputi tugas melindungi sel, tetapi juga melibatkan tugas menyamakan cas diantara sel-sel dalam kumpulan bateri. Dalam peranti elektronik, mekanisme perlindungan sel yang paling umum digunakan adalah ganguan proses caj dan discaj bateri untuk mengelakkan bateri mencapai voltan maksimum dan minimum yang dibenarkan. Ketidakseimbangan caj di antara bateri berlaku dalam bentuk voltan yang tidak sama di sepanjang bateri bersambung siri. Dua kategori utama metodologi pengimbangan sel adalah kaedah aktif dan kaedah pasif. Dalam projek ini, kedua-dua kategori pengimbangan sel akan dikaji secara meluas, dan kaedah aktif berdasarkan penukar yang cekap dan sesuai dicadangkan dan disimulasikan menggunakan MATLAB Simulink.

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LIST OF ABBREVIATIONS

AB	-	Auxiliary Battery
BBC	-	Buck Boost Converter
BC	-	Bidirectional DC-DC Converter
BMS	-	Battery Management System
C	-	Capacitance
DC	-	Direct Current
DTSC	-	Double Tiered Switched Capacitor
EV	-	Electric Vehicle
EHV	-	Electric Hybrid Vehicle
F	-	Frequency
FR	-	Fixed Resistor
MB	-	Module Balancing
M	-	Module
MSI	-	Multi Switched Inductor
MWT	-	Multi winding Transformer
RUL	-	Remaining Useful Life
SC	-	Switched Capacitor
SR	-	Shunt Resistor
SOC	-	State of Charge
SoH	-	State of Health
SSC	-	Single Switched Capacitor
SSI	-	Single Switched Inductor
SWT	-	Single Winding Transformer
T	-	Temperature
UC	-	Unidirectional DC-DC Converter
V	-	Voltage
ICE	-	Individual Cell Equalizers

LIST OF SYMBOLS

δ	-	Minimal error
T	-	Period
Ω	-	Ohm
A	-	Ampere
V	-	Voltage
D	-	Duty Cycle
f	-	Frequency
A	-	Ampere

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CHAPTER 1

INTRODUCTION

1.1 Project Background

In the modern automotive era, demand for electric cars has been rising progressively due to rising air emissions, global warming, and fossil fuel resources declining. An electric vehicle (EV) thus plays an essential part in the development of transportation since it can accomplish emissions reductions and low noise levels. The cost of electric cars varies on many factors, but the cost of the batteries is the costliest one [1]. For the secure operation of electrochemical-dependent storage systems used as batteries, a highly reliable power management system is essential. This is because enormous power and energy densities are found in these forms of storage structures [2]. Nowadays, the most popular electrical energy storage system in vehicles is lithium ion-based batteries. However, due to corrosion, passivation, outgassing, temperature, decomposition of materials, the battery power is steadily decreased [3]. The imbalances decrease the usable energy related to output induced by perturbations and diverse operational conditions. If only one lithium-ion cell is overcharged or undercharged in a battery cell, it triggers irreversible harm or accelerates the aging of cells [4].

Proper power regulation and battery management system (BMS) employed are essentials to circumvent these problems. SOC estimation, cell balancing, and thermal management are the common subsystems of the battery management systems (BMS) [5]. These subsystems are required to perform in real-time and under conditions of rapid charging and discharging. Cell balancing is a very crucial subsystem of the BMS which will efficiently prolong the battery life span. Thus, the cell balancing method not only covers the task of protecting the cells, but it also involves the task of equalizing charges between the cells. In electronic devices, the most common cell protection mechanism used is interruption of the charging and discharging process of the battery to prevent the battery from reaching its maximum and minimum permissible voltage. The charge imbalance among batteries occurs in the form of unequal voltages along the series-connected batteries.

Reliable and accurate battery operation is achieved by protecting the battery system from damage, predicting the failures, and increasing battery life by monitoring its health. A significant problem of battery system life management is the imbalance in battery pack batteries. The BMS performs multiple functions, where the measurement of V, I, T of the system, SOC, SoH, and RUL estimation of the cells, cell protection, thermal management, charge/discharge operation, data acquisition, on-board/off-board module communications, monitoring, historical data storage, and the essential importance is cell balance [6]. Figure 1.1 is an example of a BMS utilized in electric car applications.

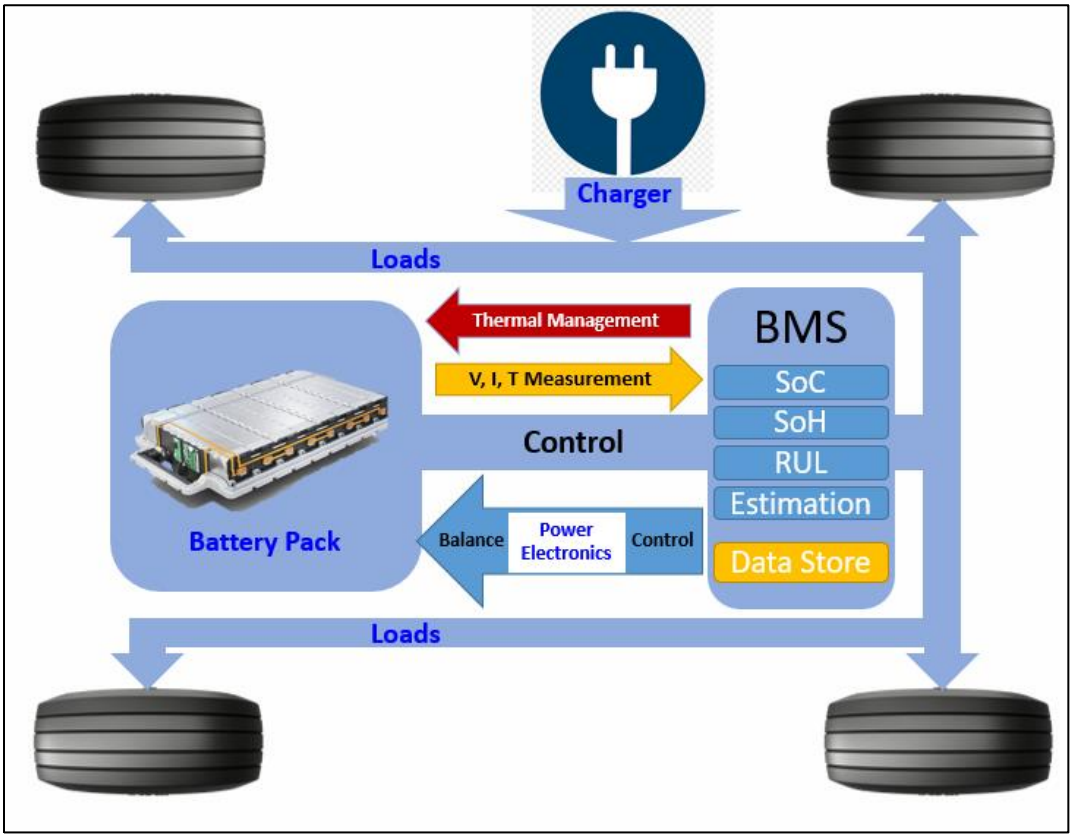

Figure 1.1 BMS Block Diagram [6]

A significant aspect impacting battery life is the imbalance of cells in battery packs. If there is no balancing mechanism available, the single-cell voltage can break apart over time. This would decrease the overall capacity of battery packs more easily during charging and discharging operation, and consequently battery device will fail permanently. Hence, cell balancing approaches are essential for maintaining battery life [1]–[11].

1.2 Problem Statement

Limitation on the manufacturing technologies plays a significant drawback of the battery characteristic where there are inequalities in terms of capacity or internal resistance between each battery pack manufactured. The imbalance parameters will result in overcharging or over-discharging the battery pack, directly affecting its performance. Thus, the life span of the entire battery pack will significantly be affected, and worst, it may cause a fire or explosion as a result of poor handling of the battery's charging and discharging process [1]–[11]. Thus, the employment of the cell balancing scheme or battery equalizer is compulsory to eliminate the cell balancing issues. Comparing to developing a new manufacturing technology that consumes more time and resources, this cell balancing approach is much more practical and economical. There are two generalized cell balancing methods, which are known as passive cell balancing and active cell balancing. Therefore, it is crucial to study and research thoroughly the various topologies of passive and active cell balancing approaches.

1.3 Project Objectives

Cell balancing is a very important feature of the battery management system (BMS). Thus, the objectives of the research are:

1. To study various passive and active cell balancing methods
2. To simulate Pack modularized active balancing topology using MATLAB Simulink with following schemes.
    a. To simulate Single Switched Capacitor (SSC) only Balancing method for balancing of cells in each module (Internal Module Balancing).
    b. To simulate a separate scheme for each internal module balancing for Single Switched Capacitor (SSC) scheme with Auxiliary Battery (AB) and Uni-directional converter (UC).
    c. To simulate module-to-module balancing for Single Switched Capacitor only, combination of Single Switched Capacitor with Auxiliary Battery (AB) and Uni-directional converter (UC).
3. To compare and analyse the simulated balancing methods.

1.4 Scope of Work

There are many methods of cell balancing or equalization have been proposed and reviewed. The scope of the works consists of:

1. Focus on study of passive and active cell balancing.
2. Focus on balancing system based on Pack Modularization
3. Focus on simulation of Single Switched Capacitor (SSC) and DC-DC Converter (Unidirectional) cell balancing topology only.
4. Battery/ cell model is based on MATLAB Simulink library.
5. DC-DC Converter Source are from Fuel cells / PV (Model with DC source for Auxiliary Battery (AB))

In the first stage, cell balancing of the cells in a pack using Single Switched Capacitor (SSC) only balancing scheme is modelled. In the second stage, the balancing of a separate scheme for each internal module balancing for Single Switched Capacitor (SSC) scheme with Buck Converter (Uni-directional converter) and Buck-Boost Converter (Uni-directional converter) is modelled and simulated. Finally, the third stage is module-to-module balancing for Single Switched Capacitor (SSC) only, the combination of Single Switched Capacitor (SSC) with Buck Converter (Uni-directional converter) and Single Switched Capacitor (SSC) with Buck-Boost Converter (Uni-directional converter) are modelled and simulated. Then, all these balancing methods are being compared and analyzed.

1.5 Project Outline

This study comprises five chapters, each of which addresses various subjects, as described below;

Chapter 1: Introduction

This chapter presents the fundamental principles of the cell balance method, its topologies, and its significance. The objectives and scopes are mentioned to provide a description of the objectives and limitations of the project.

Chapter 2: Literature Review

Passive and active cell balancing topologies suggested by different researchers are explored in depth in this chapter, including their objectives, cell balancing speed, difficulty of control, size, benefits, and drawbacks.

Chapter 3: Methodology

This chapter details the schematic and design of Modularised cell balancing method and topology used of internal module balancing and module-to-module balancing. Two methods were studied for internal module balancing, such as SSC only cell balancing topology and SSC with boost charging method. Also, this chapter details the schematic and design of the module-to-module balancing scheme using Single Switched Capacitor (SSC).

Chapter 4: Results and Discussions

This chapter provides the comparison study of numerous passive and active cell balancing methods and its advantages and disadvantages. Also presents the results from simulation of SSC only balancing method, SSC with boost charging balancing and Module-to-module balancing using SSC only and SSC with boost charging methods using MATLAB Simulink are presented and results are compared in this chapter. The results of each simulation are discussed clearly based on the speed of balancing, maximum SOC differences and energy (Wh) transfer.

Chapter 5: Conclusions

Based on the analyses and discussions provided in Chapter 4, this Chapter draws conclusions. In addition, the spectrum of potential works will be defined and outlined here.

1.6 Significant Contribution

This study has led to the improvements of cells balancing when the cells reaching the flat voltage region of the considered Lithium-ion battery by using Auxiliary Battery (AB) and Buck-boost converter within internal module balancing for Single Switch Capacitor (SSC) active balancing method. Thus, directly improve the overall time for the cell balancing in total.

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