IMPROVED COULUMB COUNTING METHOD FOR STATE OF CHARGE ESTIMATION OF LITHIUM-ION BATTERY WITH TEMPERATURE CONSIDERATION

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DEDICATION

No two things have been combined better than knowledge and patience.

(Prophet Muhammad SAW)

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ABSTRACT

In recent decades, Lithium-ion (Li-ion) battery has been dominating the battery technology in wide range of electronics application. A good utilization of battery technology comes with a proper management of its State of Charge (SOC) and state of health. Having a proper management and estimation of SOC will ensure that the life span of battery can be prolong, as well as provide the safety to the users. Therefore, it is very crucial to have an efficient and accurate SOC estimation method. This project proposes an improved Coulumb Counting (CC) method for the SOC estimation of Lithium-ion battery. The conventional CC method suffers from few drawbacks in which it strongly depends on the precision of current sensors, initial value of SOC and the nominal capacity of the battery. A lot of research has been conducted to explore the possibility of improving the CC method. Most of the methods have combined CC method with different techniques of model-based method to overcome the aforementioned drawbacks. However, the research that has been performed only cover one or two limitations at a time. Therefore, this research is conducted to study an improved CC method with the focus on diminishing these three main drawbacks of CC method. The determination of initial SOC and calibration of nominal capacity has been performed by using SOC-OCV data curve which was obtained using the discharge pulse experiment of actual 18650 Li-ion battery. Meanwhile, a temperature compensation circuit is introduced to eliminate the temperature drift of current sensor. This project simulates the effectiveness of this improved CC method using MATLAB Simulink software under wide range operating temperature. An equivalent circuit model of 18650 Li-ion battery cell is used in the simulation to study the effectiveness of proposed method. The simulation result of this improved CC method shows a slight improvement in reducing the accuracy error after implementing each of the method proposed to reduce the drawbacks of CC method. The comparison of the results between conventional CC method and improved CC method implies that the improved CC method able to reduce the disadvantageous of conventional CC method. This method is envisioned to be useful for the future engineer and designer who would like to estimate the SOC of battery using an improved CC method with a higher accuracy requirement.

ABSTRAK

Kebelakangan ini, bateri Lithium-ion (Li-ion) telah mendominasi teknologi bateri dalam pelbagai aplikasi elektronik. Penggunaan teknologi bateri yang optimum dapat dihasilkan dengan adanya pengurusan *State of Charge (SOC)* dan *State of Health (SOH)* yang betul. Mempunyai pengurusan dan anggaran SOC yang betul akan memastikan jangka hayat bateri dapat dipanjangkan, serta memberikan keselamatan kepada pengguna. Oleh itu, ianya adalah sangat penting untuk mempunyai kaedah anggaran SOC yang efisien dan tepat. Projek ini mengetengahkan kaedah Coulumb Counting (CC) yang telah ditambahbaikkan untuk anggaran SOC bateri Litium-ion. Kaedah CC konvensional mempunyai beberapa kelemahan di mana ianya sangat bergantung pada ketepatan deria arus elekrik, nilai awal SOC dan kapasiti nominal bateri. Banyak penyelidikan telah dijalankan untuk meneroka kemungkinan dalam menambahbaik kaedah CC. Kebanyakan kaedah telah menggabungkan kaedah CC dengan teknik kaedah berasaskan model untuk mengatasi kelemahan yang dinyatakan di atas. Walau bagaimanapun, penyelidikan yang telah dilakukan hanya meliputi satu atau dua kelemahan sahaja pada satu masa. Oleh itu, penyelidikan ini dijalankan untuk mengkaji kaedah CC yang dipertambahbaikkan dengan mengurangkan tiga kelemahan utama kaedah CC ini. Penentuan SOC awal dan pelarasan kapasiti nominal telah dilakukan dengan menggunakan data *State of Charge - Open Circuit Voltage (SOC-OCV)*yang diperoleh menggunakan eksperimen *discharge pulse* bateri Li-ion 18650 yang sebenar. Sementara itu, litar pampasan suhu diperkenalkan untuk mengurangkan kesilapan ukuran dari deria arus elektrik. Projek ini mensimulasikan keberkesanan kaedah CC yang dipertambahbaikkan dengan menggunakan *MATLAB Simulink* di bawah julat suhu operasi yang luas. Model litar setara sel bateri Li-ion 18650 digunakan dalam simulasi untuk mengkaji keberkesanan kaedah yang dicadangkan. Hasil simulasi kaedah CC yang ditambah baik ini menunjukkan sedikit peningkatan dalam mengurangkan ralat ketepatan selepas melaksanakan setiap kaedah yang dicadangkan untuk mengurangkan kelemahan kaedah CC. Perbandingan keputusan antara kaedah CC konvensional dan kaedah CC yang dipertambahbaikkan telah menunjukkan bahawa kaedah CC yang dipertambahbaikkan dapat mengurangkan kelemahan kaedah CC konvensional. Kaedah ini dijangka berguna untuk jurutera dan pereka masa hadapan yang ingin menganggar SOC bateri menggunakan kaedah CC yang dipertingkatkan dengan keperluan anggaran ketepatan SOC yang lebih tinggi.

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LIST OF ABBREVIATIONS

Ah	-	Ampere-hour
AKF	-	Adaptive Kalman Filter
BMS	-	Battery Management System
CC	-	Coulumb Counting
CPE	-	Constant Phase Element
DOD	-	Depth of Discharge
ECM	-	Equivalent Circuit Model
KF	-	Kalman Filter
Li-ion	-	Lithium ion
OCV	-	Open Circuit Voltage
P2D	-	Pseudo-two-Dimensional
PNGV	-	Partnership for a New Generation of Vehicle
RLS	-	Recursive Least Square
SOC	-	State of Charge
SOH	-	State of Health
SP	-	Pseudo-two-Dimensional
SP2D	-	Simplified Pseudo-two-Dimensional
TMS	-	Temperature Management System

CHAPTER 1

INTRODUCTION

1.1 Background

Over the past few decades, battery has become one of the key technologies that contributes to the expansion of many other technologies such as mobile devices, home appliance products and electric vehicles. Among of many battery types, Lithium-ion (Li-ion) has become a common type of battery being adopted in the electronics application. It is a rechargeable battery that offers a lot of advantages such as high power density, low self discharge rate, long life time and low maintenance costs. Not only that, it is also widely available in market with a high demand from consumers due to its high efficiency and low pollution [1]. Despite of those advantages, this Li-ion battery requires a protection circuit to maintain the voltage and current within its Safe Operating Area (SOA) which usually incorporated by Battery Management System (BMS). The BMS is also responsible to estimate the internal variables of battery to give a thorough understanding of its SOC and State of Health (SOH) [2]. In general, SOC is a metric that quantifies the amount of energy left within a battery cell in compared to the energy it had when it was full [3]. By having a precise SOC estimation, it can provide information to the user regarding the remaining battery duration that can be used before it needs another cycle of charging [3]. Figure 1.1 shows the block diagram of correlation between BMS and SOC [4].

Acquiring an accurate SOC estimation is an imperative process because it will prevent the battery from being over charged and over discharged which may lead to a permanent damage to the battery. By having an accurate value of SOC, it will prolong the battery life, as well as protect the users from any possibility of battery explosion. Moreover, it will also provide an insight regarding the battery performance for a period of time and therefore avoid any unpredictable system interruption. However, estimating an accurate value of SOC has becomes a challenge due to the non-linear behaviour of the

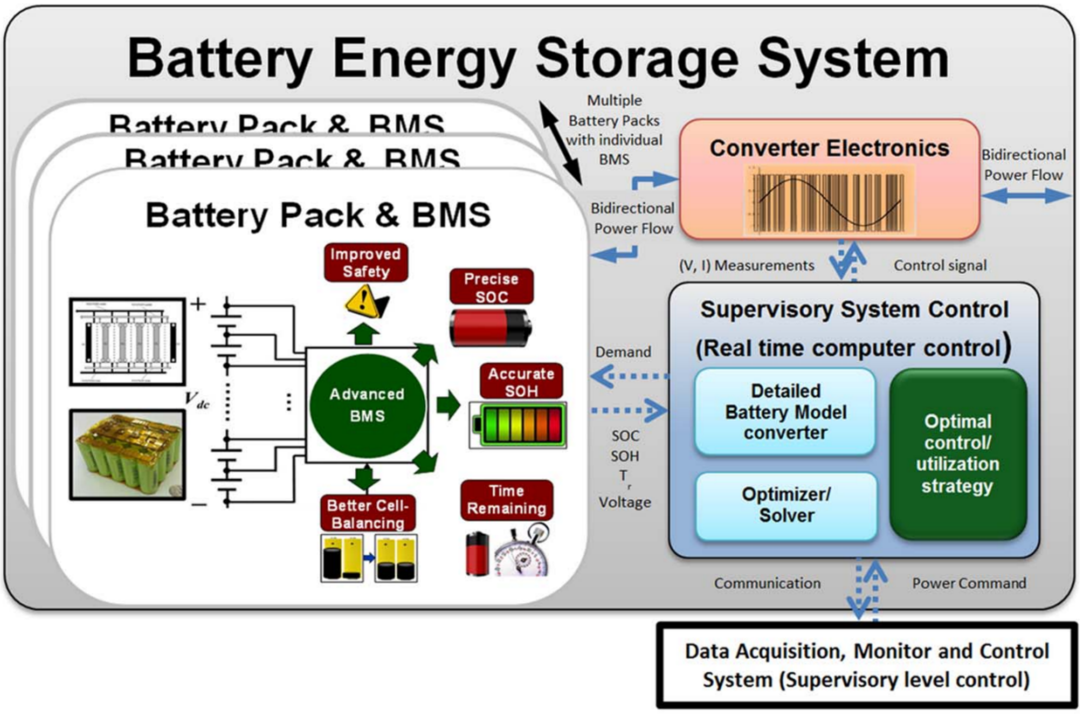

Figure 1.1 Correlation between BMS and SOC as depicted in [4]

battery cell [1] [4]. Moreover, it constantly operates outside the equilibrium state during the discharging and charging process. [4]. In every cycle of charging and discharging, the battery will experience degradation which highly depends on the temperature and its operating profile. This degradation also contributes to the complexity in determining the SOC level of the battery.

As a matter of fact, SOC cannot be measured directly from the cell, therefore, an estimation method is developed to predict the SOC level of cell [5]- [6]. Conventionally, the SOC estimation is performed by measuring the parameter of coulumb and current flowing in and out of the cell [7]. This data is then combined with the historical data from previous cell's operation to develop the precise value of SOC. Aside from that, there are few other parameters that need to be considered in order to determine the SOC. Few of the parameters include cell temperature, state operation of the cell when the measurements are being taken, cell age and few other relevant data from cell manufacturer. Usually, the parameters that need to be considered mainly depends on the method that is being employed in determining the SOC. In this research paper, the main method to be used is CC method. Therefore, the parameters that need to be considered in estimating SOC will mainly based on CC method. The accuracy of this

CC method can be deviated by not knowing the precise value of initial SOC and other parameters such as self-discharge rate and leakage effects [8]. On top of that, aging is an important parameter for the application of this method because CC method does not have the capability to follow the changes of deteriorated battery condition. Therefore, in order to determine an accurate value of SOC, it is necessary to update the reference capacity of battery cell which experiences changes due to the aging condition [8]- [9]. The estimation of SOC at varying ambient temperature should also be considered to simulate the dynamic behaviour of battery that changes accordingly with different operating condition [8].

1.2 Problem Statement

Coulumb Counting (CC) method is a common method being used to determine the SOC of Li-ion battery cell due to its simplicity and good accuracy estimation. However this method suffers from three main drawbacks; first, aggregate measurement error due to current sensor and second, unknown initial value of SOC which then causes error to the SOC value then third, cumulative error of nominal capacity. A lot of research has been conducted to seek the solution on how to improve the CC method. Most of the research has combined model based method with CC method to improve the disadvantages of CC method. However, the combined method that has been implemented previously only cover one or two drawbacks at a time. Therefore, this project is conducted to study an improved CC method with the focus on reducing the three main drawbacks.

1.3 Hypothesis

Aforementioned in Section 1.2, three main drawbacks from CC method are addressed in this project. Therefore, the methods proposed to overcome the drawbacks are as per listed below:

(i) Determination of initial SOC: Reference value from SOC-OCV curve, whereby the value obtained will be fed to the CC algorithm.

(ii) Temperature compensation error from current sensor inaccuracy: Implementation of temperature compensation circuit to the Li-ion system.

(iii) Minimization of nominal capacity error: Calibration of capacity after each cycle of its operation using SOC-OCV curve as data reference.

(iv) Main method of SOC estimation: CC method

Based on the methods mentioned above, there are several hypotheses for the research:

(i) The proposed method is able to improve the accuracy estimation of SOC by reducing the drawbacks of conventional CC method.

(ii) The proposed method is able to minimize the errors introduced by conventional CC method.

1.4 Research Objectives

The objectives of the research are:

(i) To design an improved Coulumb Counting method

(ii) To reduce the measurement errors introduced by conventional CC method.

(iii) To simulate the improved method and compare it with conventional CC method in terms of SOC accuracy.

1.5 Scope of Research

This research involves a comprehensive study of SOC estimation method of Li-ion by adopting an improved Coulumb Counting method. A hybrid method that compensates the three main drawbacks is proposed in this project. This study is performed on the Li-ion with an assumption that the battery pack is to be used in power electronics industry. Simulation using MATLAB Simulink is performed under wide ambient temperature, covers from normal room temperature to cold temperature. Hot temperature is not considered in this project. No experimental validation is performed in this project, except for data acquisition of SOC-OCV curve. Aside from that, self-discharge state of the battery is not covered in the simulation.

1.6 Research Expected Contribution

(i) The accuracy of SOC estimation is able to be improved using the methods proposed, with the accuracy error to be lower than 2%.

(ii) The hybrid method proposed is able to minimize the errors introduced by CC method.

1.7 Outline of Research Proposal

This research proposal is structured and arranged as follows:

Chapter 1 provides a general discussion of the SOC concept of Li-ion cell. Also, this chapter includes key background that is focused on in this project. The main objectives of this study and its hypotheses are described comprehensively.

Chapter 2 details a thorough literature review about the methods available in estimating SOC. This chapter focuses on conventional CC method and the improved CC method that has been implemented by other researchers. The research gap is established in this chapter which then becomes the scope being covered in this project.

Chapter 3 describes the methodology used in achieving the main objectives of the thesis. Mathematical formulation analysis and flowchart algorithm for improved CC method are described in this chapter.

Chapter 4 presents the results obtained based on the implementation of proposed improved CC method. Few cases of implementation is proposed to analyze the capability of proposed method in fulfilling the research objectives.

Chapter 5 presents the overall conclusion of this project.

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