International Journal of Automotive Technology, Vol. 24, No. 2, pp. 445–457 (2023)
DOI 10.1007/s12239–023–0037–2

pISSN 1229–9138/ eISSN 1976–3832

STATE OF CHARGE ESTIMATION OF LITHIUM-ION BATTERY USING ENERGY CONSUMPTION ANALYSIS

Shan Chen[1)], Tianhong Pan[2)*] and Bowen Jin[1)]

[1)]School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, China
[2)]School of Electrical Engineering and Automation, Anhui University, Hefei 230601, China

(Received 23 March 2022; Revised 9 May 2022; Accepted 5 October 2022)

ABSTRACT–The traditional electric current integral algorithm cannot accurately estimate a lithium-ion battery's state of charge (SOC) under complex discharge conditions. Therefore, in this study, a new estimation method based on a power integral algorithm is proposed. First, the first-order Thevenin equivalent circuit model is selected, and the energy storage and loss of the lithium-ion battery during charging and discharging operations are analyzed. Second, the inherent disadvantages of the electric current integral algorithm are analyzed, and an SOC estimation based on the power integral algorithm is presented. The error correction for the SOC estimation is derived using the extended Kalman filter (EKF). Using the established test bench, the effects of environmental temperature, state of health, and current density on the SOC estimation are analyzed. The experimental results show that the proposed method combining the power integral and EKF can accurately estimate the SOC of a lithium-ion battery.

KEY WORDS : Electric current integral algorithm, Thevenin equivalent circuit model, Extended Kalman filter, State of charge estimation, Power integral algorithm

NOMENCLATURE

SOC	: state of charge
BMS	: battery management system
HPPC	: hybrid pulse power characteristic
SOH	: state of health
UDDS	: urban dynamometer driving schedule
EKF	: extended kalman filter
CFD	: computational fluid dynamics
PNGV	: partnership for a new generation of vehicles
GNL	: general nonlinear
OCV	: open circuit voltage

1. INTRODUCTION

Lithium-ion batteries have the advantages of high energy, high specific power, low self-discharge rate, and no memory effects. They are widely used in various fields, including energy storage (Chen *et al*., 2020) and transportation (Zhang *et al*., 2018). The state of charge (SOC) characterizes the remaining capacity of the battery, and its estimation is an essential component of battery management systems (BMSs) (Li *et al*., 2020). However, the SOC estimation accuracy depends on the battery model and corresponding estimation method (Wang *et al*., 2019).

The chemical reaction inside a battery is a very complicated nonlinear process, and it is difficult to describe its characteristics. Several models of it have been presented in the literature, including electrical, electrochemical, finite element, and computational fluid dynamics (CFD) models (Lakghomi *et al*., 2015); these all feature a simple and intuitive electrical model. Xu and Fen (2019) analyzed the advantages and disadvantages of various battery models, including Rint, Thevenin, Partnership for a New Generation of Vehicles (PNGV), and general nonlinear (GNL). The Rint model does not reflect the transient response of the battery, and its accuracy fails to meet the requirements. The computational burdens of the GNL and PNGV models are too large to be applied in industrial processes. The Thevenin circuit model has the characteristics of a variant order: its estimated accuracy varies with the model order. Thus, it can reflect the transient response of the battery, which makes it amenable to SOC estimation (Zhong *et al*., 2017).

There are many types of battery SOC estimation methods, including open circuit voltage (OCV), empirical formulas and mathematical models, electrochemical impedance spectroscopy, neural networks, and electric current integral methods. Lee *et al*. (2008) reported that the OCV method requires a long time to reset after the battery has been discharged. Liu *et al*. (2015) proposed an empirical formula

**Corresponding author*. e-mail: thpan@ahu.edu.cn