Recent Progress and Future Trends on the State of Charge Estimation Methods to Improve Battery-storage Efficiency: A Review

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***Abstract*—Battery storage systems are subject to frequent charging/discharging cycles, which reduce the operational life of the battery and reduce system reliability in the long run. As such, several Battery Management Systems (BMS) have been developed to maintain system reliability and extend the battery's operative life. Accurate estimation of the battery's State of Charge (SOC) is a key challenge in the BMS due to its non-linear characteristics. This paper presents a comprehensive review on the most recent classifications and mathematical models for SOC estimation. Future trends for SOC estimation methods are also presented.**

***Index Terms*—Battery Management System (BMS), battery modeling, battery storage efficiency, state of charge (SOC).**

I. Introduction

WITH the global trend to replace fossil fuel-based electricity generation by renewable energy sources, developing reliable energy storage systems have been prioritized in the agenda of worldwide utilities, manufacturers and researchers. Among various storage systems, battery technology has seen a revolution during the last decade due to its low greenhouse effect, high power density and low self-discharging rate [1], [2]. Reference [3] proposed a water and battery storage system for 100% renewable energy generation in Saudi Arabia by the year 2040. The Li-Ion battery (LIB) has supplanted other types such as lead-acid, Ni-MH, Ni-Cd batteries because of its superior technical advantages in the face of energy density factors. While the LIB features high power capacity and extended life cycle, a reliable battery energy management system (EMS) is essential to maintain its efficiency and reliability along with its entire operational life [4]–[6].

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Reference [7] presented a review on an EMS for the applications of LIB in electrical vehicles (EV). In an EMS, state of charge (SOC) of the battery is a key parameter that identifies the entire operational life of the battery. Reference [8] reviewed various methods of the SOC estimation for EV applications. The BMS observes the state of the battery cells and employs several algorithms to precisely normalize the charging-discharging process. References [9] and [10] presented various SOC estimation techniques for LIB and suggested some guidance for future research. SOC estimation can identify the maximum charging-discharging process to maintain the consistency and extend the effective life of the battery along with improving the State of Health (SOH), State of Function (SOF) and body-temperature [11].

II. Battery Modeling

A linear discrete-time state-space procedure is necessary to estimate the SOC of the battery as shown in Fig. 1(a) and the below equations:

$$x_{p+1} = A_p x_p + B_p u_p + w_p \tag{1}$$

$$y_p = C_p x_p + D_p u_p + v_p \tag{2}$$

where $x_p \in$ real number R^n is the system state vector at discrete-time index p, $u_p \in R^n$ is the system input, $w_p \in R^n$ is unmeasured stochastic "process noise" which distresses the system state, $y_p \in R^n$ is the system output as well as $v_p \in R^n$ is the measurement noise that affects the model output. A_p, B_p, C_p, D_p represents the dynamics of the system that depend on specific time-varying battery models.

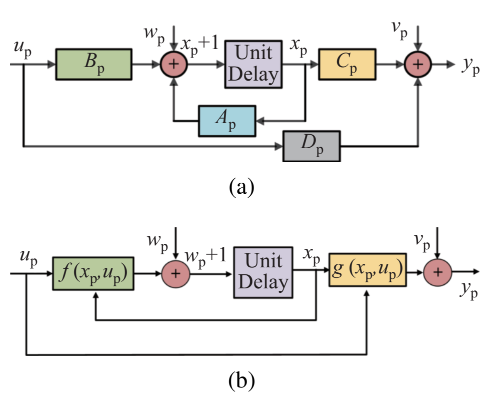

Fig. 1. (a) Linear discrete-time system; (b) Nonlinear discrete-time system.