

Abstract

As the world seeks solutions to reduce greenhouse gas emissions and enhance air quality, the significance of transportation electrification is growing. Electric vehicles (EVs) are identified as a pivotal response to these challenges, as they have the potential to mitigate emissions and pollution inherent in traditional gasoline and diesel vehicles. However, the efficacy and durability of EV batteries constitute a fundamental determinant of their viability. The accurate assessment of a vehicle battery's state of charge (SOC) and state of health (SOH) stands as a critical facet in the management and maintenance of these batteries, particularly in on-road and second-life applications. Precise SOC and SOH estimation can play a pivotal role in optimizing battery performance and lifespan, a crucial factor for the sustained success of EVs. Nonetheless, the estimation of SOC and SOH in vehicle battery energy storage systems is a complex undertaking owing to various factors such as battery degradation, temperature influences, charge/discharge rates, battery age, battery models, system complexity, and second-life applications.

The primary objective of this dissertation is to devise an effective and accurate methodology for estimating SOC and SOH of battery cells and packs through data-driven approaches. The proposed solution harnesses machine learning algorithms and is adaptable for real-time and offline deployment, both on-board and off-board. This research endeavors to bridge the current gap in scalable and versatile algorithms for SOC and SOH estimation, applicable to diverse battery types and environmental conditions. The intent is to offer a holistic design framework for integrating these algorithms into practical applications such as electric vehicles, stationary systems, and engine starting, thereby serving as a guide for researchers and practitioners navigating the landscape of battery health and performance monitoring.

The dissertation begins with identifying the subject under examination, which could encompass a single battery cell or a cluster of cells forming a pack. Subsequently, the operational parameters, including temperature and current profiles, are delineated to facilitate data acquisition pertaining to battery performance. This dataset serves as the basis for training machine learning algorithms for accurate SOC and SOH estimation. The proposed approach is versatile, finding application both in real-time scenarios where batteries function within vehicles or systems, and data can be gathered during operation, as well as in offline scenarios where batteries are removed for controlled laboratory testing.

Specifically focusing on lead-acid batteries in heavy-duty trucks, the research leverages Artificial Neural Networks for regression and classification tasks to estimate SOC and SOH. The algorithms are meticulously devised, validated through simulation, and tested in real-world operational settings. Demonstrating their efficacy, the SOC and SOH estimation accuracy registers at less than 3% and 4% respectively during testing under actual operational conditions.

Moreover, the dissertation confronts the escalating necessity for alternative applications or recycling options at the conclusion of a battery's initial lifecycle. It introduces a self-contained platform for assessing the SOH of used lithium-ion batteries. This platform can swiftly provide SOH estimates by analyzing health indicators derived from current and voltage measurements subsequent to discharging the battery using an impulse current profile. The platform boasts a remarkable estimation accuracy exceeding 96%.

A pivotal contribution of this dissertation is the formulation of a comprehensive approach for designing SOC and SOH estimation methods within battery storage systems. This approach transcends the algorithms themselves, encompassing the entirety of the workflow from data collection to hardware implemen-

tation. Such a holistic perspective is indispensable for real-world applicability, as the hardware prerequisites and testing conditions must be meticulously addressed to ensure dependable and precise outcomes. The dissertation further underscores the significance of tailoring methodologies to the specific attributes and requisites of varying battery chemistries and sizes. The versatile design approach delineated herein strives to accommodate an extensive array of battery types, thus enabling researchers and practitioners to apply the same methodology across diverse battery categories. In essence, this dissertation offers a comprehensive and practical framework for SOC and SOH estimation within battery storage systems, facilitating application in real-world scenarios and serving as a guidepost for those seeking to enhance technologies for monitoring energy storage system health and performance.