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Battery management solutions for li-ion batteries based on artificial intelligence

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ABSTRACT

The automobile industry is currently undergoing a paradigm change from conventional, diesel, and gasoline-powered vehicles to hybrid and electric vehicles of the second generation. Lithium-ion (Li-ion) batteries have sparked the automotive industry's interest for quite some time. One of the most crucial components of an electric car is the battery management system (BMS). Since the battery pack is an electric vehicle's most significant and expensive component, it must be carefully monitored and controlled. The precise measurement and calculation of the many states of a Li-ion battery's cells, such as the State of Health (SOH) and State of Charge (SOC) is a difficult procedure as they cannot be monitored directly. This paper examines various methodologies and approaches for estimating the SOC and SOH of Li-ion batteries using Artificial Intelligent methods. Six machine learning algorithms are intensively utilized to investigate the Li-ion battery state estimation. The employed methods are linear, random forest, gradient boost, light gradient boosting (light-GBM), extreme gradient boosting (XGB), and support vector machine (SVM) regressors. In comparison to all other models employed in this study, the discharge prediction made using random forest exhibits significantly greater performance at a low loss of accuracy. For instance, with the highest R2-score of 0.999, the random forest regressor achieves only 0.0035, 0.0013, and 0.0097 for mean and median absolute error, and root means squared error (RMSE), respectively. We showed that the state estimation of Li-ion batteries can be precisely predicted using AI methods, which can be combined with a battery management system to improve electric vehicle performance.

1. Introduction

Because of overexploitation in several sectors, particularly transportation and energy, worldwide stocks of fossil fuels are rapidly depleting. Overexploitation of fossil fuels produces massive volumes of CO_2 and other Green House Gas Emissions (GHGE), which has had a significant impact on the environment and contributed to climate change. The GHGE can be decreased by up to 40% [1] with the use of renewable energy and the electrification of the transportation sector. Due to the irregular nature of renewable energy sources such as wave, wind, tidal, and solar, an energy storage system (ESS) is used to make the supply to the customer more reliable [2–8]. (SEE Table 1.).

The Electric Vehicle (EV) as shown in Fig. 1 is thought to be the answer to reducing the hazardous pollution emissions from automobiles. Additionally, because electric vehicles can be utilized as energy storage systems to store energy from renewable energy sources, they can engage actively with the electrical grid [9]. This is known as vehicle-to-grid (V2G) interaction. In recent years, many chemistries of energy storage systems (ESSs) have been approved for use in transportation [10]. Li-ion batteries, nickel–cadmium batteries, and lead acid batteries are the most commonly used batteries in EVs. However, Li-ion batteries have grown in

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Table 1
List of Abbreviations and Symbols.

Abbreviations	
SOC	State of Charge
SOH	State of Health
Li-ion	Lithium-ion
BMS	Battery Management System
ESS	Energy Storage System
EV	Electric Vehicle
FLS	Neuro-Fuzzy Systems
ES	Expert Systems
SVM	Support Vector Machine
EA	Evolutionary Algorithm
HIS	Hybrid Intelligent Systems
ANN	Artificial Neural Network
AI	Artificial Intelligence
XGB	Extreme Gradient Boosting
Light-GBM	Light Gradient Boosting
SEI	Solid Electrolyte Interphase
V2G	Vehicle-to-Grid
RMSE	Root Means Squared Error
MSE	Means Squared Error
ML	Machine learning
GHGE	Green House Gas Emissions
Symbols	
E_{oc}	Open circuit voltage
V_{term}	Battery terminal voltage
R_0	Series resistance in battery equivalent circuit
R_m	m^{th} parallel resistance in RC branch in battery equivalent circuit
C_m	m^{th} parallel capacitance in RC branch in battery equivalent circuit
$i(t)$	applied current to the battery equivalent circuit
$i_m(t)$	Current flowing through the m^{th} RC branches
K	Gain of the transfer function
b_i	Numerator parameters of the transfer function
a_i	Denominator parameters of the transfer function
$B(s)$	Battery transfer function
$v(s)$	Battery voltage in the Laplace domain
$i(s)$	Battery current in the Laplace domain

Fig. 1. A Standard Electric Vehicle.

popularity as a result of their increased dependability, power density, energy density, efficiency, longer lifespan, reduced discharge rates, and high efficiency [11]. Another significant element contributing to the widespread commercialization of Li-ion batteries is their decreasing manufacturing costs, which supports their use in a variety of industries [12].

Li-ion batteries have been employed in the ESSs ranging in size from a few kilowatt-hours in household systems to multi-megawatt batteries in power grids [13]. Despite its potential for usage in energy storage solutions, Li-ion batteries have a few limitations, including the need for a battery pack's safe operating zone, which is dependent on a precise SOC estimate. When cells are grouped in large numbers in either series or parallel modules in a battery stack to provide increased power output based on requirements, the pack's safety is critical [17]. If Li-ion batteries are utilized beyond their safety tolerances, they can deteriorate and ultimately become a hazard.

A Battery Management System (BMS) is a set of software and hardware designed to improve a battery's charge and discharge cycles while also extending its life [15]. For our needs, the BMS calculates and monitors two crucial metrics. The first is the State of Health (SOH), which depicts the battery's performance in comparison to its past and anticipated future. The State of Charge (SOC) refers to the amount of charge in a battery throughout a charge or discharge cycle. Neither of the parameters can be measured directly [16]. There are several methods for determining the SOH and SOC of a battery pack. Data-driven methods, model-based methods, or even advanced sensing-based methods can be used to estimate SOC and SOH.

When it comes to the design of BMS in EVs, accurate battery pack parameter estimations are crucial and important; they also provide some important supplementary data, such as the remaining life or useable time [17]. BMSs also prevent Li-ion batteries from being overcharged or discharged. Because the Li-ion battery is a complex, nonlinear, and time-varying electrochemical system, its performance varies as operating conditions change, such as charge–discharge current, aging, and fluctuations [18]. Since direct interaction with a sensor is not a possibility, precise calculation of SOC and SOH for a Li-ion battery is a difficult task.

The traditional battery management approaches have two fundamental flaws. The first disadvantage is that you must use numbers from "baseline" models, which represent the average of the laboratory results [19]. In real-world applications, batteries exhibit a wide range of attributes over a wide range of operating situations. As a result, the accuracy of traditional models is limited [20]. Furthermore, as batteries age, their properties alter, increasing the model's ineptitude even more. The second disadvantage is that the parameters of the battery must be computed while the battery is "offline," or out of operation, for the duration of the measurements [21]. For state estimate and prediction in BMS, current research is aiming to use numerous additional options such as Computational Intelligence, Artificial Intelligence (AI), and others [22].

The importance of artificial intelligence and its following components has long been recognized. As a result, during the functioning of parts incorporating this technology, manual involvement is the last thing that may be requested or observed. These machines accelerate activities and processes while ensuring precision and accuracy making them a valued and helpful tool. As established earlier due to the increased popularity of Li-ion batteries, it is imperative to develop different algorithms to estimate SOC and SOH due to the non-linear nature of a Li-ion battery. In our work we leverage this opportunity to make the following key contributions:

1. We perform an extensive literature review of the diverse AI technologies employed in battery management systems.
2. We investigate six AI strategies: ANN, FLS, ES, SVM, EA, and HIS to develop an advanced AI strategy for accurate prediction of battery's SOC and SOH in EVs.
3. We perform a comparative analysis of the different AI techniques employed based on several metrics to determine the best AI strategy for accurate estimation of battery's state in EVs.

The rest of the paper is organized as follows. Section 2 delves into the internal model of the battery. Section 3 examines the fundamentals of BMS and analyses the various AI approaches used in