

Precise Parameter Identification of Lithium-ion Battery Models for Electric Vehicle Applications

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Abstract—Lithium-ion batteries (LiBs) have become the leading choice for energy storage systems (ESS) in electric vehicles (EVs) due to their superior performance characteristics. However, their sensitivity compared to other battery technologies necessitates the use of advanced battery management systems (BMS) for reliable and safe operation. Accurate parameter identification for LiBs is essential to assess the performance of energy storage systems within BMSs and EVs. This research explores the Fully Informed Search Algorithm (FISA), a novel optimization method, to determine the parameters of 2nd and 3rd order equivalent circuit models (ECM) for LiBs. As an enhanced version of the Rao algorithm, FISA is recognized for its efficiency in tackling real-world optimization problems while maintaining the simplicity and parameter-free nature of its predecessor. The study focuses on minimizing the error between the ECM-predicted voltage and the actual battery voltage measurements. To validate the proposed approach, a high dynamic profile (HDP) is employed, alongside a comparative analysis of FISA and the Rao algorithm. The simulation results demonstrate that FISA achieves highly accurate and stable parameter estimation, surpassing the precision of the Rao method. Moreover, findings indicate that the 3rd order ECM provides superior accuracy in capturing the parameters of the battery model.

Keywords—Battery Model, Metaheuristic, Energy storage, Parameters estimation, Artificial Intelligence, FISA algorithm.

I. INTRODUCTION

The global shift towards renewable energy sources has become imperative in addressing the environmental, economic, and political challenges associated with traditional fossil fuels. Technologies such as solar, wind, and tidal energy are pivotal in reducing carbon emissions and advancing sustainable energy systems [1], [2]. However, the intermittent and unpredictable nature of renewable energy necessitates the integration of energy storage systems to ensure stability and reliability in power grids. Lithium-ion batteries (LiBs) have emerged as a leading energy storage solution due to their superior performance characteristics, including high energy density, long lifespan, fast charging capabilities, and minimal self-discharge rates [3], [4]. LiBs are extensively utilized in electric vehicles (EVs), which play a vital role in the transition to cleaner transportation systems. However, the integration of EVs into modern power systems and smart grids introduces several challenges. Among these is the need for precise battery modeling to ensure accurate dynamic analysis and efficient energy management [5]. Accurate models, such as Equivalent Circuit Models (ECMs), are essential for simulating the

behavior of LiBs and optimizing their performance. These models provide a simplified yet effective representation of a battery's electrical behavior, making them a cornerstone for Battery Management Systems (BMS) [6].

A sophisticated BMS is crucial for monitoring critical battery parameters—such as state of charge (SOC), and state of health (SOH)—and ensuring the safety, reliability, and longevity of LiBs [7]. Accurate parameter estimation is fundamental for ECMs to reflect the battery's nonlinear and complex electrochemical characteristics. However, this task remains a significant challenge due to the intricate nature of LiBs and the dynamic conditions in which they operate. Developing advanced methods for parameter identification is essential to enhance battery performance, improve energy efficiency, and facilitate the seamless integration of EVs into renewable energy systems and smart grids [8].

In recent years, the rapid advancements in Artificial Intelligence (AI) have transformed problem-solving methodologies in engineering, particularly for tackling large-scale and complex optimization challenges. Among the most prominent AI techniques are Metaheuristic Algorithms (MAs), which take inspiration from natural and biological processes to develop innovative solutions. These algorithms have been effectively applied to various engineering domains, such as the welding process [9], image processing [10], parameter estimation for PEM fuel cells [11], [12], and photovoltaic modeling [13]. Optimization methods, in particular, have become critical for estimating battery parameters, delivering exceptional improvements in precision and computational efficiency. A wide array of MA techniques has been utilized for this purpose, including the walrus optimization algorithm [1], gazelle optimization algorithm [3], adolescent identity search algorithm [4], Rao-1 algorithm [5], information sharing group teaching optimization algorithm [6], Honey Badger Algorithm [8], Bald Eagle Search [14] and hybrid method [15]. These techniques have proven effective for estimating parameters in Equivalent Circuit Models (ECMs) of batteries, demonstrating their potential to achieve accurate and optimized outcomes. The use of diverse MAs provides researchers with the flexibility to explore and select algorithms tailored to specific parameter estimation scenarios. However, despite their advantages, existing MA-based optimization algorithms often face limitations in certain problem domains, presenting opportunities to refine existing methods or develop entirely new frameworks. According to the No Free Lunch Theorems (NFLTs), no single algorithm can outperform all others across