Enhanced State of Charge Recognition in Li-ion Batteries Using a Novel Stochastic Model

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Abstract

This study proposes a stochastic model for the state-of-charge of a Li-ion battery, aiming to explore the model's dynamic behavior and the embedded parameters. The proposed state-of-charge stochastic model constructed in this study can be used to quickly probe the rest energy of Li-ion batteries in the dynamic applications. Furthermore, designing a proper controller based on this model can effectively enhance the performance and lifespan of the Li-ion battery. Notably, this study is one of the few that adopts a stochastic modeling perspective in building battery models. As a result, it introduces several innovative attempts in the realm of sensor signal processing.

I. Introduction

The Introduction of this paper highlights the significance of lithium-ion batteries in modern technology and emphasizes the challenges in accurately predicting their State of Charge (SOC). Lithium-ion batteries, widely used in applications like electric vehicles, exhibit complex electrochemical properties that make SOC prediction difficult. The SOC of a battery is influenced by various factors such as ambient temperature, current load, and other chemical parameters, leading to inconsistencies in its measurement. In certain applications, particularly electric vehicles, an accurate SOC prediction is crucial for performance and safety. Traditional methods often struggle to handle the inherent variability and nonlinearity of lithium-ion batteries' behavior. Therefore, researchers have turned to stochastic modeling approaches to better capture and predict the dynamic changes in SOC. This paper points out that while SOC is commonly defined within the range (0, 1), the study proposes a mathematical transformation that allows for more flexible modeling of SOC as a stochastic process. By using a stochastic approach, including Brownian motion and Poisson processes, the authors aim to build a model that can describe the dynamic and random fluctuations in the battery's SOC over time. This paper introduces this new stochastic model, which differs from traditional deterministic models, as it incorporates random events and uncertainties that better reflect real-world operating conditions. The main goal of this research is to provide a model that can more effectively predict the remaining energy in a lithium-ion battery in dynamic applications, such as electric vehicles. Moreover, the authors propose that by designing a suitable controller based on this stochastic model, the overall performance and lifespan of the battery can be significantly enhanced. Overall, this paper sets the stage for the research by explaining the importance of accurate SOC prediction, the limitations of existing methods, and the potential of the proposed stochastic model to address these challenges. The novel approach taken in this study is framed as a significant contribution to the field of battery modeling and sensor signal processing.

II. Results

The **Main Results** of this paper outlines several key findings from the study, which are summarized as follows:

1. **Stochastic Model for SOC**: The paper presents a stochastic model that effectively captures the dynamic behavior of a lithium-ion battery's State of Charge (SOC). The model incorporates both Brownian motion and Poisson processes to describe the random fluctuations and jumps in SOC, providing a more accurate representation of the battery's performance under various conditions. This approach is novel in the field of battery modeling.
2. **Long-term Behavior of SOC**: Under specific conditions related to the estimating factors μ and σ, the study demonstrates that the SOC will eventually stabilize at zero as time approaches infinity. This finding suggests that over extended periods, the battery will naturally discharge, aligning with real-world battery behavior.
3. **Controllability of the Stochastic Model**: The study shows that the proposed SOC model is controllable, meaning that, with the appropriate control parameters, the SOC of a battery can be effectively managed and predicted. This is an important finding for practical applications, as it means that the battery's energy usage can be optimized through proper control mechanisms.
4. **Consistency of Parameter Estimations**: The paper provides results proving that the estimations of key parameters, such as the drift μ and volatility σ, are consistent. This means that as the number of observations increases, the estimated parameters converge to the true values. This finding is critical for ensuring the reliability and accuracy of the model in practical applications.
5. **Numerical Simulations**: The authors validate their model through numerical simulations. For example, the drift and volatility values obtained from the simulations align well with the predicted theoretical values. Additionally, the paper presents a simulated SOC curve that shows how the SOC evolves over time during a charging process. The model accurately captures the random fluctuations and overall trend of the SOC.
6. **Implications for Battery Performance**: By using the stochastic model, it becomes possible to enhance both the performance and lifespan of lithium-ion batteries. The ability to predict SOC more accurately and manage energy usage more effectively could lead to significant improvements in battery-based applications, such as electric vehicles.

III. Conclusions

The study concludes that the proposed model provides a strong theoretical foundation for understanding SOC in a stochastic framework and presents a groundbreaking method for sensor signal processing in battery applications. The authors suggest that future work will include verification experiments to test the practical feasibility of the model and further refine the approach based on experimental data.