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Lyapunov-Based Adaptive State of Charge and State of Health Estimation for Lithium-Ion Batteries

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Extended Abstract:

Lithium-ion batteries have received an increasing interest from the scientific community thanks to their small size, light weight, rapid charge capability, long life cycle, wide temperature operation range, low steady-state float current, low self-discharge rate, no memory effects, and absence of hydrogen outgassing. But, the accuracy of State of charge (SOC) and state of health (SOH) algorithms remains an important aspect in battery management systems (BMS) because a bad SOC estimation might significantly damage the battery and ultimately result in reduced battery life.

Conventional SOC estimation techniques are known for their simplicity. The coulomb counting method, which is also called ampere-hour (Ah) balancing method, is a rational way to estimate a battery's SOC. However, start-up and current sensor errors are accumulated, which leads to a drift and poor precision, since the process is open-loop based. This method has some serious drawbacks. Nevertheless, it remains the simplest approach for real-time industrial applications. On the other hand, open-circuit voltage (OCV) can be used to determine a battery SOC since it is correlated with the battery's charge status. However, this is true only when the battery reaches an equilibrium state. A combination between the aforementioned two methods yields a hybrid estimation technique. Thus, the coulomb counting method is used in operation and whenever the battery reaches an equilibrium state, the SOC is updated with the OCV method to reset accumulated errors. However, some applications require a continuous operation and do not allow batteries to reach an equilibrium state. This raises the urgency of considering other SOC estimation alternatives. Several robust and accurate estimation techniques are proposed at the cost of higher computational complexity such as, reduced-order observers, adaptive observers, sliding mode observers, and so on. Moreover, soft-computing methodologies, such as neural networks and fuzzy logic, have been applied for the SOC and SOH estimation problem, which have led to a satisfactory performance. But these techniques lack stability proof and their tuning might not be trivial.

Unlike aforementioned methods, this work proposes an adaptive SOC and SOC estimation approach with guaranteed stability. The adaptive strategy consists of a Lyapunov-based adaptation law for online parameter estimation. Therefore, the battery OCV and impedance are estimated since they vary with SOC and SOH, respectively. Thus, robustness to parametric uncertainties is achieved, which yields better accuracy as the battery ages compared to classical methods. In this paper, a Lyapunov stability-based estimation technique is proposed. Thus, stability is guaranteed unlike many classical and computational intelligence-based estimation strategies. Therefore, the proposed adaptive estimation technique achieves high accuracy and robustness, while reducing the computational burden associated with machine learning based techniques, which makes it realizable at low cost. Furthermore, the proposed method requires only battery voltage and current measurement, which reduces the number of sensors, with respect to other methods. Simulation and experimental results highlight the high SOC and SOH accuracy estimation of the proposed technique.

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