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Systematic experimental pulse test investigation for parameter identification of an equivalent circuit based lithium-ion battery model

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Abstract

The paper presents an equivalent circuit based simulation model for the static and dynamic behavior of lithium-ion battery systems and explains the different steps of the theoretical and experimental modeling process. The equivalent circuit based model describes the voltage-current characteristic, the state of charge behavior and the occurring losses of the battery system. A parameter identification method based on three characteristic experiments, a cycle test, an open circuit voltage test and pulse tests, is introduced. The model parameters are estimated employing a nonlinear optimization method. Furthermore, the experimental test bed for investigation of lithium-ion battery systems is described. The battery model approach is demonstrated and validated for a commercial 5 kWh lithium-ion battery system, including the model validation for test profiles and emulated battery charging and discharging profiles of a real photovoltaic home storage application. The comparison of measured and simulated voltage profiles indicates an excellent performance of the battery model.

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Keywords: lithium-ion battery, modeling, equivalent circuit model, parameter identification, current-pulse, experimental testbed

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1. Introduction

Due to their high energy density, long cycle-life and efficient charge and discharge behavior lithium-ion batteries play an important role in many different kind of energy storage applications. They are increasingly used in the consumer sector (cellphones, laptops, camcorders), the rising e-mobility sector (hybrid and full electric vehicles), as well as in storage solutions for the optimal utilization and grid integration of renewable energies such as wind and photovoltaics (PV) [1]. PV-home storage systems based on lithium-ion battery technology offer a great opportunity for an improved operation with higher self-sufficiency and self-consumption, active limitation of grid feed-in power and back-up power functionality [2, 3]. Lithium-ion batteries can also be employed in off-grid and hybrid energy storage systems [4-6]. For the optimal sizing [7] and energy management of battery and hybrid energy storage systems adequate simulation models are required that reflect the electrical, thermal and aging behavior (s. Fig. 1).

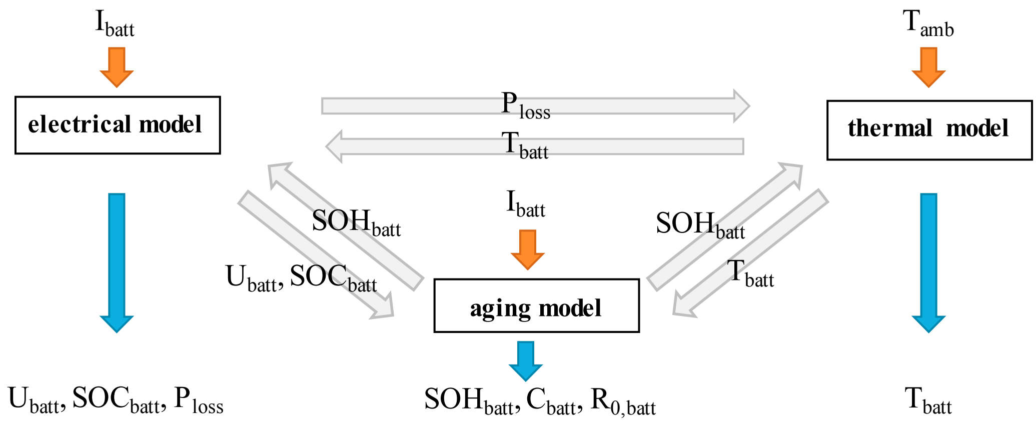

Fig. 1. Principle structure of a lithium-ion battery system model [8].

Model inputs are the battery current I_{batt} and the ambient temperature T_{amb}. Model outputs are the voltage U_{batt}, the state of charge SOC_{batt}, the temperature T_{batt}, the state of health SOH_{batt}, the available capacity C_{batt}, the internal resistance $R_{0,batt}$, and the occurring losses P_{loss} of the battery. The lithium-ion battery model consists of three sub-models that are depending on each other, the electrical model, the thermal model and the aging model. This paper only focusses on the electrical sub-model.

Different modeling approaches for the electrical behavior of lithium-ion batteries have been suggested and published. They significantly vary in complexity and accuracy. Three main groups of battery models can be distinguished, physico-chemical models [9, 10], empiric models [11, 12], and impedance based models [13-21]. Physico-chemical models characterize the chemical process inside the battery employing differential equations. This approach is very complex, and it takes a long computing time for a simulation. Another way to model the battery behavior is the utilization of an empiric approach. The relationship between the internal battery parameters and the battery voltage is formulated with functional relationships. Impedance based models characterize the battery behavior with equivalent circuits. An electrical circuit network consisting of a voltage source, resistors and capacitors is easily to be implemented and describes the dynamic behavior of the battery with high accuracy. The equivalent circuit based battery model with a realistic description of the static and dynamic battery behavior, limited number of model parameters, a simple implementation and an adaptability for different technologies (iron phosphate, titanate, manganese) will be applied.

This paper is organized as follows, section 2 describes the lithium-ion battery model. Section 3 presents the identification method focusing on the required specific tests and experiments and the description of the parameter estimation algorithm employing a nonlinear optimization method. Section 4 explains the experimental test bed for investigation of various lithium-ion battery systems. Section 5 presents the results of measurements and model identification process for an example of a commercial 5 kWh lithium-ion battery system, including the discussion of the model validation