

Accurate Electrical Battery Model Capable of Predicting Runtime and I - V Performance

Min Chen, *Student Member, IEEE*, and Gabriel A. Rincón-Mora, *Senior Member, IEEE*

Abstract—Low power dissipation and maximum battery runtime are crucial in portable electronics. With accurate and efficient circuit and battery models in hand, circuit designers can predict and optimize battery runtime and circuit performance. In this paper, an accurate, intuitive, and comprehensive electrical battery model is proposed and implemented in a Cadence environment. This model accounts for all dynamic characteristics of the battery, from nonlinear open-circuit voltage, current, temperature, cycle number, and storage time-dependent capacity to transient response. A simplified model neglecting the effects of self-discharge, cycle number, and temperature, which are nonconsequential in low-power Li-ion-supplied applications, is validated with experimental data on NiMH and polymer Li-ion batteries. Less than 0.4% runtime error and 30-mV maximum error voltage show that the proposed model predicts both the battery runtime and I - V performance accurately. The model can also be easily extended to other battery and power sourcing technologies.

Index Terms—Batteries, cadence simulation, electrical model, I - V performance, nickel-metal hydride battery, polymer lithium-ion battery, runtime prediction, test system.

I. INTRODUCTION

ELECTROCHEMICAL batteries [1] are of great importance in many electrical systems because the chemical energy stored inside them can be converted into electrical energy and delivered to electrical systems, whenever and wherever energy is needed. Although the popularity of portable electronics like cell phones, PDAs, digital cameras, and laptop computers has propelled battery technologies, such as nickel cadmium (NiCd), nickel-metal hydride (NiMH), lithium-ion (Li-ion), and polymer Li-ion [2], those battery technologies cannot yet meet the progressive energy demands and size limitations of today's portable electronics [3].

A primary concern in the design of portable electronics is how to minimize power dissipation and extend battery runtime [4]. Without circuit and battery models in hand, circuit designers can neither predict nor optimize either battery runtime or circuit performance. Although accurate and efficient electrical models of circuits and systems at different levels of abstraction have been developed and also have been implemented in some electronic design automation (EDA) tools, like in Cadence design systems, an accurate, intuitive, and comprehensive electrical battery model is not available, especially in circuit simulators,

because of the complicated physical and dynamic properties of batteries [1].

A battery model capable of predicting both the runtime and I - V performance can be used to design energy-aware circuits and systems [5], optimize circuit and system performance [6], [7], predict battery runtime for different load profiles [8], emulate batteries with electronic circuits [9], and improve battery energy efficiency [10]. The proposed model predicts all the important properties and is compatible with lead-acid, NiCd, NiMH, Li-ion, polymer Li-ion, and other electrochemical batteries. More importantly, its ability to be conveniently simulated with other circuits and systems in Cadence-compatible simulators allows for optimum system designs and simulations. With minor modifications, this model can be extended to fuel cells and other power sources.

This paper is organized as follows. Section II reviews state of the art in battery models. Section III introduces the proposed model and explains the significance of the various model parameters. Section IV describes a battery test system and an experimental procedure used to extract the various model parameters. Finally, Section V presents the extracted model parameters, Section VI validates the proposed model by comparing simulation results with experimental data, and Section VII concludes the paper.

II. BACKGROUND

Researchers around the world have developed a wide variety of models with varying degrees of complexity. They capture battery behavior for specific purposes, from battery design and performance estimation to circuit simulation. Electrochemical models [11]–[14], mainly used to optimize the physical design aspects of batteries, characterize the fundamental mechanisms of power generation and relate battery design parameters with macroscopic (e.g., battery voltage and current) and microscopic (e.g., concentration distribution) information. However, they are complex and time consuming because they involve a system of coupled time-variant spatial partial differential equations [13]—a solution for which requires days of simulation time, complex numerical algorithms, and battery-specific information that is difficult to obtain, because of the proprietary nature of the technology.

Mathematical models [8], [10], [15]–[18], mostly too abstract to embody any practical meaning but still useful to system designers, adopt empirical equations or mathematical methods like stochastic approaches [10] to predict system-level behavior, such as battery runtime, efficiency, or capacity. However, mathematical models cannot offer any I - V information that is important to circuit simulation and optimization. In addition,

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