

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

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**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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**European Space Agency**



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*Microgrid Technologies* Chenniappan Sharmeela, Palanisamy Sivaraman, Sanjeevikumar Padmanaban, Jens Bo Holm-Nielsen, 2021-03-10 Microgrid technology is an emerging area and it has numerous advantages over the conventional power grid. A microgrid is defined as Distributed Energy Resources (DER) and interconnected loads with clearly defined electrical boundaries that act as a single controllable entity concerning the grid. Microgrid technology enables the connection and disconnection of the system from the grid. That is, the microgrid can operate both in grid-connected and islanded modes of operation. Microgrid technologies are an important part of the evolving landscape of energy and power systems. Many aspects of microgrids are discussed in this volume, including in the early chapters of the book: the various types of energy storage systems, power and energy management for microgrids, power electronics interface for AC/DC microgrids, battery management systems for microgrid applications, power system analysis for microgrids, and many others. The middle section of the book presents the power quality problems in microgrid systems and its mitigations, gives an overview of various power quality problems and its solutions, describes the PSO algorithm-based UPQC controller for power quality enhancement, describes the power quality enhancement and grid support through a solar energy conversion system, presents the fuzzy logic-based power quality assessments, and covers various power quality indices. The final chapters in the book present the recent advancements in the microgrids applications of Internet of Things (IoT) for microgrids, the application of artificial intelligent techniques, modeling of green energy smart meter for microgrids, communication networks for microgrids, and other aspects of microgrid technologies. Valuable as a learning tool for beginners in this area as well as a daily reference for engineers and scientists working in the area of microgrids, this is a must-have for any library.

*Electric Vehicle Integration into Modern Power Networks* Rodrigo Garcia-Valle, João A. Peças Lopes, 2012-11-29 *Electric Vehicle Integration into Modern Power Networks* provides coverage of the challenges and opportunities posed by the progressive integration of electric drive vehicles. Starting with a thorough overview of the current electric vehicle and battery state of the art, this work describes dynamic software tools to assess the impacts resulting from the electric vehicles deployment on the steady state and dynamic operation of electricity grids, identifies strategies to mitigate them, and the possibility to support simultaneously large scale integration of renewable energy sources. New business models and control management architectures, as well as the communication infrastructure required to integrate electric vehicles as active demand, are presented. Finally, regulatory issues of integrating electric vehicles into modern power systems are addressed. Inspired by two courses held under the EES UETP umbrella in 2010 and 2011, this contributed volume consists of nine chapters written by leading researchers and professionals from the industry as well as academia.

**Sliding Mode Control** Andrzej Bartoszewicz, 2011-04-11 The main objective of this monograph is to present a broad range of well-worked-out recent application studies, as well as theoretical contributions in the field of sliding mode control system analysis and design. The contributions presented here include new

theoretical developments as well as successful applications of variable structure controllers primarily in the field of power electronics electric drives and motion steering systems They enrich the current state of the art and motivate and encourage new ideas and solutions in the sliding mode control area

**Next-generation Batteries with Sulfur Cathodes** Krzysztof Jan Siczek, 2019-03-06 Next Generation Batteries with Sulfur Cathodes provides a comprehensive review of a modern class of batteries with sulfur cathodes particularly lithium sulfur cathodes The book covers recent trends advantages and disadvantages in Li S Na S Al S and Mg S batteries and why these batteries are very promising for applications in hybrid and electric vehicles Battery materials and modelling are also dealt with as is their design the physical phenomena existing in batteries and a comparison of batteries between commonly used lithium ion batteries and the new class of batteries with sulfur cathodes that are useful for devices like vehicles wind power aggregates computers and measurement units Provides solutions for the recycling of batteries with sulfur cathodes Includes the effects of analysis and pro and cons of Li S Na S Al S Mg S and Zn S batteries Describes state of the art technological developments and possible applications

*Energy and Sustainability VI* W.F. Florez-Escobar, C.A. Brebbia, F. Chejne, F. Mondragon, 2015-09-02 Diverse topics covered in this title containing the conference proceedings of the 6th International Conference on Energy and Sustainability involve interdisciplinary cooperation to arrive at optimum solutions including materials energy networks new energy resources storage solutions waste to energy systems smart grids and many others Energy and Sustainability VI focuses on energy matters and the need to respond to the modern world s dependency on conventional fuels The continuous use of fossil fuels has generated an increasing amount of interest in renewable energy resources and the search for sustainable energy policies This book also presents the following topics Sustainable Energy Production Energy in the Built Environment Energy Production Energy Networks Smart Grids and Metering Energy Storage and Policies Shale Oil and Gas Oil Sands Processes CO2 Capturing and Management Energy Management Imbedded Energy in Manufacturing Energy and Transportation Energy Efficiency Renewable Energy Resources Biomass and Biofuels Waste to Energy The Future of Nuclear Energy Environmental Risk Greener Power Plant Technologies Optimization of Conventional Energy Resources Advances in Energy Production

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*Batteries* Ronald K Jurgen, 2010-11-29 With production and planning for new electric vehicles gaining momentum worldwide this book the second in a series of five volumes on this subject provides engineers and researchers with perspectives on the most current and innovative developments regarding electric and hybrid electric vehicle technology design considerations and components This book features 15 SAE technical papers published from 2008 through 2010 that provide an overview of research on electric vehicle batteries Topics include Charging strategy studies for PHEV batteries Electric vehicle and hybrid electric vehicle rechargeable energy storage

systems Strategies for reducing plug in battery costs Cold temperature performance Lithium ion battery power capability testing crash safety and modeling

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*Energy-Aware System Design* Chong-Min Kyung,Sungjoo Yoo,2011-06-17  
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Proceedings of the European Space Power Conference: Photovoltaic generators, energy storage European Space Agency, 1995 Dynamic Simulation of Electric Vehicle Performance Nickolas Mota Melville, 1995 **Proceedings of ASP-DAC/VLSI Design 2002**, 2002 Papers from a January 2002 conference are organized into four sessions each on low power design synthesis testing layout and interconnects and technology as well as two sessions each on embedded systems verification and VLSI architecture one session on analog design and one session on hot c **Pesc'80 Record**, 1980

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## **Table of Contents An Accurate Electrical Battery Model Capable Of Predicting**

1. Understanding the eBook An Accurate Electrical Battery Model Capable Of Predicting
  - The Rise of Digital Reading An Accurate Electrical Battery Model Capable Of Predicting
  - Advantages of eBooks Over Traditional Books
2. Identifying An Accurate Electrical Battery Model Capable Of Predicting
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an An Accurate Electrical Battery Model Capable Of Predicting
  - User-Friendly Interface
4. Exploring eBook Recommendations from An Accurate Electrical Battery Model Capable Of Predicting
  - Personalized Recommendations
  - An Accurate Electrical Battery Model Capable Of Predicting User Reviews and Ratings
  - An Accurate Electrical Battery Model Capable Of Predicting and Bestseller Lists
5. Accessing An Accurate Electrical Battery Model Capable Of Predicting Free and Paid eBooks
  - An Accurate Electrical Battery Model Capable Of Predicting Public Domain eBooks
  - An Accurate Electrical Battery Model Capable Of Predicting eBook Subscription Services
  - An Accurate Electrical Battery Model Capable Of Predicting Budget-Friendly Options

6. Navigating An Accurate Electrical Battery Model Capable Of Predicting eBook Formats
  - ePub, PDF, MOBI, and More
  - An Accurate Electrical Battery Model Capable Of Predicting Compatibility with Devices
  - An Accurate Electrical Battery Model Capable Of Predicting Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of An Accurate Electrical Battery Model Capable Of Predicting
  - Highlighting and Note-Taking An Accurate Electrical Battery Model Capable Of Predicting
  - Interactive Elements An Accurate Electrical Battery Model Capable Of Predicting
8. Staying Engaged with An Accurate Electrical Battery Model Capable Of Predicting
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers An Accurate Electrical Battery Model Capable Of Predicting
9. Balancing eBooks and Physical Books An Accurate Electrical Battery Model Capable Of Predicting
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection An Accurate Electrical Battery Model Capable Of Predicting
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine An Accurate Electrical Battery Model Capable Of Predicting
  - Setting Reading Goals An Accurate Electrical Battery Model Capable Of Predicting
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of An Accurate Electrical Battery Model Capable Of Predicting
  - Fact-Checking eBook Content of An Accurate Electrical Battery Model Capable Of Predicting
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
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- Interactive and Gamified eBooks

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