

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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An Accurate Electrical Battery Model Capable Of Predicting

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An Accurate Electrical Battery Model Capable Of Predicting:

Ein Beitrag zur Erhöhung der Reichweite eines batterieelektrischen Fahrzeugs durch prädiktives Thermomanagement Markus Auer, 2016-03-21 Markus Auer diskutiert Maßnahmen, die den bereits sehr guten Wirkungsgrad batterieelektrischer Fahrzeuge weiter steigern. Dabei untersucht der Autor nicht nur konventionelles Thermomanagement, sondern auch Vorkonditionierungen, sondern stattdessen das Thermomanagement zudem mit einer vorausschauenden Komponente aus. Darüber hinaus entwickelt er eine Notfallfunktion, die das Fahrziel auch dann erreichbar macht, wenn sich dieses außerhalb der momentanen Reichweite befindet. Zur Analyse der Energiebilanz wird eine Kennzahl hergeleitet, mit der die optimale Durchschnittsgeschwindigkeit für eine maximale Reichweite bestimmt werden kann.

Modellierung von Fahrzeugantrieben anhand von Messdaten aus dem Koppelbetrieb zwischen Fahr Simulator und Antriebsstrangprüfstand Andreas Schmidt, 2016-03-30 Andreas Schmidt zeigt neue Möglichkeiten zur Entwicklung, Erprobung und Modellierung von Fahrzeugantriebssträngen auf. Durch die Verbindung von Fahr Simulator und Antriebsstrangprüfstand werden die jeweiligen Vorteile der beiden Werkzeuge kombiniert und gleichzeitig deren Einschränkungen umgangen. Zu den Vorzügen zählen insbesondere die bessere Messtechnik am Prüfstand, das Fehlen unerwünschter Störungen, keine Gefährdung von Verkehrsteilnehmern und die Reduzierung der Zahl benötigter Fahrzeugprototypen. Die gegenseitigen Wechselwirkungen zwischen Fahrer und Antriebsstrang können im Koppelbetrieb in neuartiger Qualität untersucht werden, da beide Komponenten real vorhanden sind.

Beitrag zur Bewertung des Gesundheitszustands von Traktionsbatterien in Elektrofahrzeugen Phan-Lam Huynh, 2016-11-16 Phan Lam Huynh stellt eine universelle Methode zur Bewertung von Traktionsbatterien in Hybrid und Elektrofahrzeugen ohne externe Sensorik vor. Basierend auf ausführlichen Grundlagenuntersuchungen am Batterieprüfstand identifiziert er einen Indikator für die Bewertung von Traktionsbatterien in Hybrid und Elektrofahrzeugen. Der Autor realisiert die Erfassung der Werte im Fahrzeug über ein geführtes Diagnoseverfahren. Die Bewertung der Traktionsbatterie erfolgt durch einen lernenden Algorithmus. Den praktischen Nachweis der auf weiteren Fahrzeugmodellen übertragbaren Methode führt Huynh an zwei Fahrzeugmodellen mit über 350 Testobjekten durch.

The Emerging Form of Smart Grid: Smart Integrated Energy Systems and Prosumer Centred Energy Community Tao Huang, Ciwei Gao, Chenghong Gu, Yingjun Wu, 2022-07-07

New Applications of Electric Drives Miroslav Chomat, 2015-12-09 In the last few decades electric drives have found their place in a considerable number of diverse applications. They are successfully replacing some other traditional types of drives owing to their better performance and excellent controllability. The introduction of electric drives is in most cases also beneficial from the ecological point of view as they are not directly dependent on fossil fuels and an increasing part of electric energy they consume is generated in renewable energy sources. This book focuses on applications of electric drives that emerged only recently and on novel aspects that appear in them. Particular attention is given to using electric drives in vehicles, aircraft, non-road mobile

machinery and HVAC systems 13th International Munich Chassis Symposium 2022 Peter Pfeffer, 2024-04-29 The increasing automation of driving functions and the electrification of powertrains present new challenges for the chassis with regard to complexity redundancy data security and installation space At the same time the mobility of the future will also require entirely new vehicle concepts particularly in urban areas The intelligent chassis must be connected electrified and automated in order to be best prepared for this future Contents Redundant Systems and Testing New Systems and Concepts New Chassis and Systems Simulators Automated Driving Development Methods Automated Driving Driver and Security Steer by Wire Environmental Aspects New Brake Concepts and Methods Environmental Aspects Tires and the Environment Innovations in Tires and Wheels Vehicle Dynamics Digital Development Future Brake Systems Tires and Virtual Development Target audiences Automotive engineers and chassis specialists as well as students looking for state of the art information regarding their field of activity Lecturers and instructors at universities and universities of applied sciences with the main subject of automotive engineering Experts researchers and development engineers of the automotive and the supplying industry Publisher ATZ live stands for top quality and a high level of specialist information and is part of Springer Nature one of the leading publishing groups worldwide for scientific educational and specialist literature Partner T V S D is an international leading technical service organisation catering to the industry mobility and certification segment

Cyber-Physical Microgrids Yan Li, 2021-10-20 This textbook provides students with an overview of cyber physical microgrid networks and an in depth introduction to photovoltaics batteries flywheel supercapacitor micro turbines wind generation power electronic interfaces modeling and stability analysis of microgrids and cyber communication networks and security The text helps upper level undergraduate and graduate students gain a foundational understanding of microgrids and renewable energy and offers an introduction to the frontier of theoretical research and practical applications of cyber physical systems paving the way to uncover and understand the operational mechanism of cyber physical microgrids The book includes examples and test systems throughout for problem solving and will be an essential resource for students researchers and professionals in power engineering **Modern Battery Engineering: A Comprehensive Introduction** Kai Peter Birke, 2019-04-05 This is a book primarily for engineers and materials scientists either researching or developing Li ion energy storage batteries who want to understand some of the critical aspects of Li ion battery technology and gain knowledge about the latest engineering designs and latest materials being used in Li ion batteries Good technical depth many tables of data and many illustrations combined with references at the end of each chapter for further in depth study make this book worth reading to gain a quick understanding of the current state of the art in Li ion battery technology and the fundamental issues and challenges facing Li ion battery designers IEEE Electrical Insulation Magazine This richly illustrated book written by Professor Kai Peter Birke and several co authors addresses both scientific and engineering aspects of modern batteries in a unique way Emphasizing the engineering part of batteries the book acts as a compass

towards next generation batteries for automotive and stationary applications The book provides distinguished answers to still open questions on how future batteries look like Modern Battery Engineering explains why and how batteries have to be designed for successful commercialization in e mobility and stationary applications The book will help readers understand the principle issues of battery designs paving the way for engineers to avoid wrong paths and settle on appropriate cell technologies for next generation batteries This book is ideal for training courses for readers interested in the field of modern batteries

Photovoltaic Power System Weidong Xiao, 2017-05-05 Photovoltaic Power System Modelling Design and Control is an essential reference with a practical approach to photovoltaic PV power system analysis and control It systematically guides readers through PV system design modelling simulation maximum power point tracking and control techniques making this invaluable resource to students and professionals progressing from different levels in PV power engineering The development of this book follows the author's 15 year experience as an electrical engineer in the PV engineering sector and as an educator in academia It provides the background knowledge of PV power system but will also inform research direction Key features Details modern converter topologies and a step by step modelling approach to simulate and control a complete PV power system Introduces industrial standards regulations and electric codes for safety practice and research direction Covers new classification of PV power systems in terms of the level of maximum power point tracking Contains practical examples in designing grid tied and standalone PV power systems Matlab codes and Simulink models featured on a Wiley hosted book companion website

Proceedings of Symposium on Power Electronic and Renewable Energy Systems Control Sankarsan Mohapatra, Jonathan Kimball, 2021-07-09 This book includes high quality research papers presented at Symposium on Power Electronic and Renewable Energy Systems Control PERESC 2020 which is held at the School of Electrical Sciences IIT Bhubaneswar Odisha India during 4-5 December 2020 The book covers original work in power electronics which has greatly enabled integration of renewable and distributed energy systems control of electric machine drives high voltage system control and operation The book is highly useful for academicians engineers researchers and students to be familiar with the latest state of the art in power electronics technology and its applications

Optimal Energy Management Strategies for Reconfigurable Batteries Nejmeddine Bouchhima, 2021-05-10 Lithium Ionen Batterien werden aufgrund ihrer hohen Energie und Leistungsdichte häufig in Elektrofahrzeugen und stationären Speichersystemen eingesetzt Allerdings müssen die Batteriezellen aufgrund der Kapazitätstreuung ausgeglichen werden Die Einzelzellschalter Topologie die die Aktivierung und Deaktivierung jeder Batteriezelle basierend auf ihrem aktuellen Zustand ermöglicht gilt als vielversprechende Lösung um die Inhomogenität der Batteriezellen zu bewerkstelligen Ziel dieser Arbeit ist die Entwicklung von optimalen Energiemanagement Strategien für die Einzelzellschalter Batterie um die Energieeffizienz des Systems zu maximieren Für die Berechnung des globalen Optimums wird ein Optimierungsalgorithmus basierend auf der dynamischen Programmierung Methode entwickelt Diese Strategie ist eine nicht kausale Strategie da die Batterieleistungsanforderungen

ber den Optimierungshorizont für die Strategie bekannt sein müssen In einer Simulationsumgebung werden diese Informationen eines vorgegebenen Fahrprofils entnommen Als nächster Schritt werden zwei statische Optimierungsprobleme von dem dynamischen Optimierungsproblem abgeleitet damit die Entwicklung von kausalen Energiemanagement Strategien ermöglicht werden kann Diese Strategien berechnen ein lokales Optimum da sie keine Informationen über den gesamten Fahrzyklus verwenden

QoS in Wireless Sensor/Actuator Networks and Systems Mário Alves, 2018-11-26 This book is a printed edition of the Special Issue QoS in Wireless Sensor Actuator Networks and Systems that was published in JSAN

Handbook of Power Electronics in Autonomous and Electric Vehicles Muhammad H. Rashid, 2024-07-22 Handbook of Power Electronics in Autonomous and Electric Vehicles provides advanced knowledge on autonomous systems electric propulsion in electric vehicles radars and sensors for autonomous systems and relevant aspects of energy storage and battery charging The work is designed to provide clear technical presentation with a focus on commercial viability It supports any and all aspects of a project requiring specialist design analysis installation commissioning and maintenance services With this book in hand engineers will be able to execute design analysis and evaluation of assigned projects using sound engineering principles and commercial requirements policies and product and program requirements Presents core power systems and engineering applications relevant to autonomous and electric vehicles in characteristic depth and technical presentation Offers practical support and guidance with detailed examples and applications for laboratory vehicular test plans and automotive field experimentation Includes modern technical coverage of emergent fields including sensors and radars battery charging and monitoring and vehicle cybersecurity

Linear and Nonlinear System Modeling Tamal Roy, Suman Lata Tripathi, Souvik Ganguli, 2024-09-06 Written and edited by a team of experts in the field this exciting new volume presents the cutting edge techniques latest trends and state of the art practical applications in linear and nonlinear system modeling Mathematical modeling of control systems is essentially extracting the essence of practical problems into systematic mathematical language In system modeling mathematical expression deals with modeling and its applications It is characterized that how a modeling competency can be categorized and its activity can contribute to building up these competencies Mathematical modeling of a practical system is an attractive field of research and an advanced subject with a variety of applications The main objective of mathematical modeling is to predict the behavior of the system under different operating conditions and to design and implement efficient control strategies to achieve the desired performance A considerable effort has been directed to the development of models which must be understandable and easy to analyze It is a very difficult task to develop mathematical modeling of complicated practical systems considering all its possible high level non linearity and cross couple dynamics Although mathematical modeling of nonlinear systems sounds quite interesting it is difficult to formulate the general solution to analyze and synthesize nonlinear dynamical systems Most of the natural processes are nonlinear having very high computational complexity of several numerical issues It is impossible to create any

general solution or individual procedure to develop exact modeling of a non linear system which is often improper and too complex for engineering practices Therefore some series of approximation procedures are used in order to get some necessary knowledge about the nonlinear system dynamics There are several complicated mathematical approaches for solving these types of problems such as functional analysis differential geometry or the theory of nonlinear differential equations

Smart Power Grids 2011 Ali Keyhani, Mohammad Albaijat, 2012-01-12 Electric power systems are experiencing significant changes at the worldwide scale in order to become cleaner smarter and more reliable This edited book examines a wide range of topics related to these changes which are primarily caused by the introduction of information technologies renewable energy penetration digitalized equipment new operational strategies and so forth The emphasis will be put on the modeling and control of smart grid systems The book addresses research topics such as high efficiency transformers wind turbines and generators fuel cells or high speed turbines and generators

Thermal Management for Batteries Hafiz Muhammad Ali, 2024-03-15 Thermal Management of Batteries presents a comprehensive examination of the various conventional and emerging technologies used for thermal management of batteries and electronics With an emphasis on advanced nanofluids the book provides step by step guidance on advanced techniques at the component and system level for both active and passive technology Starting with an overview of the fundamentals each chapter quickly builds into a comprehensive treatment of up to date technologies The first part of the book discusses advanced battery technologies while the second part addresses the design and performance optimization of battery thermal management systems Power density and fast charging mechanisms of batteries are considered as are role of thermal management systems on performance enhancement The book discusses the design selection of various thermal management systems parameters selection for different configurations the operating conditions for different battery types the setups used for experimentation and instrumentation and the operation of thermal management systems Advanced techniques such as heat pipes phase change materials nanofluids novel heat sinks and two phase flow loops are examined in detail Presenting the fundamentals through to the latest developments alongside step by step guidance mathematical models schematic diagrams and experimental data Thermal Management of Batteries is an invaluable and comprehensive reference for graduates researchers and practicing engineers working in the field of battery thermal management and offers valuable solutions to key thermal management problems that will be of interest to anyone working on energy and thermal heat systems Critically examines the components of batteries systems and their thermal energy generation Analyzes system scale integration of battery components with optimization and better design impact Explores the modeling aspects and applications of nanofluid technology and PCMs as well as the utilization of machine learning techniques Provides step by step guidance on techniques in each chapter that are supported by mathematical models schematic diagrams and experimental data

Languages, Design Methods, and Tools for Electronic System Design Rolf Drechsler, Robert Wille, 2016-05-30 This book brings together a selection of the

best papers from the eighteenth edition of the Forum on Specification and Design Languages Conference FDL which took place on September 14-16, 2015 in Barcelona, Spain. FDL is a well-established international forum devoted to dissemination of research results, practical experiences, and new ideas in the application of specification, design, and verification languages to the design, modeling, and verification of integrated circuits, complex hardware, software, embedded systems, and mixed technology systems.

Proceedings of 2023 7th Chinese Conference on Swarm Intelligence and Cooperative Control Yongzhao Hua, Yishi Liu, Liang Han, 2024-06-14. This book includes original peer-reviewed research papers from the 2023 7th Chinese Conference on Swarm Intelligence and Cooperative Control CCSICC2023 held in Nanjing, China, on November 17-19, 2023. The topics covered include but are not limited to reviews and discussions of swarm intelligence, basic theories on swarm intelligence, swarm communication and networking, swarm perception, awareness, and location, swarm decision and planning, cooperative control, cooperative guidance, swarm simulation and assessment. The papers showcased here share the latest findings on theories, algorithms, and applications in swarm intelligence and cooperative control, making the book a valuable asset for researchers, engineers, and university students alike.

Practical Battery Design and Control Naoki Matsumura, 2023-02-28. Battery technologies play a vital role in day-to-day life, and with the continued growth of the battery market, there is an increasing demand for a comprehensive text such as this that encompasses aspects of electrochemistry, materials science, physical chemistry, and machine learning. Aimed at early to mid-career battery engineers, this book addresses common problems that are likely to be encountered on the job. This book discusses several topics, including the prediction of battery longevity, how to extend battery life with machine learning algorithms, cost reduction, and sustainability, and battery charging problems relating to wearables, electric vehicles, drones, smart phones, laptops, and portable devices. Designed to help readers obtain practical knowledge through intuitive explanations and broad coverage of battery topics, this one-of-a-kind book is a must-have resource for practicing battery engineers throughout their career.

Energy Storage Ahmed F. Zobaa, 2013-01-23. Besides new methods of generating energy, the storage of that energy is a highly important topic with new technologies in great demand. This book offers readers a range of potential options, maximizing the possibility for success. Several chapters offer overviews of the future of such systems and estimations of their feasibility. Forms of energy storage covered include electrochemical, compressed air, and flywheel systems. Other techniques addressed are the use of single and double switch cell voltage equalizers and hybrid energy storage and applications. Dynamic energy storage methods are also covered by two chapters. Finally, there are contributions on a low-voltage DC system with storage and distributed generation interfaced systems and the in situ dynamic characterization of energy storage and conversion systems.

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