

Nonlinear Control of Electric Machines: An Overview

David G. Taylor

Due to the increasing availability of improved power electronics and digital processors at reduced costs, there has been a trend to seek higher performance from electric machine systems through the design of more sophisticated control systems software. There exist significant challenges in the search for improved control system designs, however, since (i) the dynamics of most electric machine systems exhibit significant nonlinearities, (ii) not all state variables are necessarily measured, and (iii) the parameters of the system can vary significantly from their nominal values. In recent years, a wide range of nonlinear methods for feedback control, state estimation, and parameter identification have emerged, and some of these results are reviewed and summarized in this article.

Introduction

Electric machines are electromechanical energy converters, used for both motor drives and generating systems. Nearly all electric power used throughout the world is generated by so-called synchronous machines (operated as generators), and a large fraction of all this electric power is consumed by so-called induction machines (operated as motors). There are many other types of electric machines, though, distinguished by the materials used, certain key construction features, and the underlying principles of operation.

The first DC machine was constructed by Faraday around 1820, the first practical version was made by Henry in 1829, and the first commercially successful version was introduced in 1837. The three-phase induction machine was invented by Tesla around 1887. Although improved materials and manufacturing methods continue to refine electric machines, it is safe to say that the fundamental issues relating to electromechanical energy conversion have been established for well over a century.

In such an apparently well-established field, it may come as a surprise that today there is more research and development activity related to electric machine systems than ever before. Included in a modern electric machine system is the electric machine itself, power electronic circuits, electrical and/or mechanical sensors, and digital processors equipped with various software algorithms. The recent developments in power semiconductors, digital electronics, and permanent-magnet materials have led to "enabling technology" for today's advanced electric machine systems. But the increasing use of computers, both for

the design of electric machines and for their real-time control, is now contributing more to the level of innovation in electric machine systems than perhaps any other factor.

This article attempts to provide an overview of recent developments in control systems design for electric machines operated as motor drives. The article takes a broad perspective in the sense that the wide variety of different machine types is considered, hopefully from a unifying point of view. On the other hand, in order to limit the scope substantially, an effort was made to focus specifically on the more recent nonlinear control methods, as opposed to the classical methods, which have less potential for achieving high-dynamic performance. An unavoidable limitation of the presentation is a lack of depth and detail in the descriptions of individual achievements; however, the intention was to highlight nonlinear control technology for electric machines to a broad audience, and to guide the interested reader to the appropriate sources for further study.

To put the control design problem into perspective, the article begins with a discussion of electric machine modeling, with emphasis on a generic formulation that can be further specialized to specific machine types as needed. The most commonly made simplifications available for electric machine models are reviewed, and the practical issue of model parameterization is also considered. The next topic addressed is (state-feedback) control design for electric machines and, for purposes of organization, the recent nonlinear methodologies are divided into three groups: exact linearization design, energy shaping design, and backstepping and manifold design. Most, if not all, of the recently reported electric machine control contributions can be roughly placed within these groups. Finally, the roles of parameter identifiers and state observers for electric machine control are briefly discussed.

The list of references included is by no means exhaustive, and is intended only to represent some key publications for each of the topics addressed within the confining structure of this overview article. Although each of the references cited presumably could provide useful background information, two references in particular deserve special mention. The survey/challenge paper [46], dating back to 1986, not only provides clear descriptions of modeling, estimation, and control issues for electric machines that are still relevant today, it also contains an extensive bibliography and would make a helpful supplement to the present article. Also, a very recent special issue of *Proceedings of the IEEE*, [10], contains a collection of informative papers spanning the broad areas of power electronics and motion control.

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Nonlinear Control Of Electric Machinery

**Ewald F. Fuchs, Mohammad A. S.
Masoum**



Nonlinear Control Of Electric Machinery:

Nonlinear Control of Electric Machinery Dawson, 2019-01-22 This work presents nonlinear control algorithms for a benchmark mechanical system actuated by different types of electric machinery emphasizing system stability and robustness pivotal in the development of optimal position trajectory controllers for common motors College or university bookstores may order five or more copies at a special student price available on request from Marcel Dekker *Nonlinear Control of Electric Machinery* D. M. Dawson, Jun Hu, Timothy C. Burg, 1998 **Modeling and High Performance Control of Electric Machines** John Chiasson, 2005-05-13 Modeling and High Performance Control of Electric Machines introduces you to both the modeling and control of electric machines The direct current DC machine and the alternating current AC machines induction PM synchronous and BLDC are all covered in detail The author emphasizes control techniques used for high performance applications specifically ones that require both rapid and precise control of position speed or torque You ll discover how to derive mathematical models of the machines and how the resulting models can be used to design control algorithms that achieve high performance Graduate students studying power and control as well as practicing engineers in industry will find this a highly readable text on the operation modeling and control of electric machines An Instructor s Manual presenting detailed solutions to all the problems in the book is available from the Wiley editorial department Instructor Support materials are also available Email IAl@wiley.com **Nonlinear Control of Electric Machines** James Joseph Carroll (Jr), 1994 The Control Handbook William S. Levine, 1996-02-23 This is the biggest most comprehensive and most prestigious compilation of articles on control systems imaginable Every aspect of control is expertly covered from the mathematical foundations to applications in robot and manipulator control Never before has such a massive amount of authoritative detailed accurate and well organized information been available in a single volume Absolutely everyone working in any aspect of systems and controls must have this book **Nonlinear Control of Electric Machines** James Joseph Carroll, 1993 **Control System Applications** William S. Levine, 2018-10-24 Control technology permeates every aspect of our lives We rely on them to perform a wide variety of tasks without giving much thought to the origins of the technology or how it became such an important part of our lives Control System Applications covers the uses of control systems both in the common and in the uncommon areas of our lives From the everyday to the unusual it s all here From process control to human in the loop control this book provides illustrations and examples of how these systems are applied Each chapter contains an introduction to the application a section defining terms and references and a section on further readings that help you understand and use the techniques in your work environment Highly readable and comprehensive Control System Applications explores the uses of control systems It illustrates the diversity of control systems and provides examples of how the theory can be applied to specific practical problems It contains information about aspects of control that are not fully captured by the theory such as techniques for protecting against controller failure and the role of cost and complexity in

specifying controller designs *Sensorless AC Electric Motor Control* Alain Glumineau, Jesús de Leon Morales, 2015-03-16 This monograph shows the reader how to avoid the burdens of sensor cost reduced internal physical space and system complexity in the control of AC motors Many applications fields electric vehicles wind and wave energy converters and robotics among them will benefit *Sensorless AC Electric Motor Control* describes the elimination of physical sensors and their replacement with observers i e software sensors Robustness is introduced to overcome problems associated with the unavoidable imperfection of knowledge of machine parameters resistance inertia and so on encountered in real systems The details of a large number of speed and or position sensorless ideas for different types of permanent magnet synchronous motors and induction motors are presented along with several novel observer designs for electrical machines Control strategies are developed using high order sliding mode and quasi continuous sliding mode techniques and two types of observer controller schemes based on backstepping and sliding mode techniques are described Experimental results validate the performance of these observer and controller configurations with test trajectories of significance in difficult sensorless AC machine problems Control engineers working with AC motors in a variety of industrial environments will find the space and cost saving ideas detailed in *Sensorless AC Electric Motor Control* of much interest Academic researchers and graduate students from electrical mechanical and control engineering backgrounds will be able to see how advanced theoretical control can be applied in meaningful real systems **Vector Control of Three-Phase AC Machines** Nguyen Phung Quang, Jörg-Andreas Dittich, 2015-05-14 This book addresses the vector control of three phase AC machines in particular induction motors with squirrel cage rotors IM permanent magnet synchronous motors PMSM and doubly fed induction machines DFIM from a practical design and development perspective The main focus is on the application of IM and PMSM in electrical drive systems where field orientated control has been successfully established in practice It also discusses the use of grid voltage oriented control of DFIMs in wind power plants This second enlarged edition includes new insights into flatness based nonlinear control of IM PMSM and DFIM The book is useful for practitioners as well as development engineers and designers in the area of electrical drives and wind power technology It is a valuable resource for researchers and students *AC Electric Motors Control* Fouad Giri, 2013-03-25 The complexity of AC motor control lies in the multivariable and nonlinear nature of AC machine dynamics Recent advancements in control theory now make it possible to deal with long standing problems in AC motors control This text expertly draws on these developments to apply a wide range of model based control design methods to a variety of AC motors Contributions from over thirty top researchers explain how modern control design methods can be used to achieve tight speed regulation optimal energetic efficiency and operation reliability and safety by considering online state variable estimation in the absence of mechanical sensors power factor correction machine flux optimization fault detection and isolation and fault tolerant control Describing the complete control approach both controller and observer designs are demonstrated using advanced nonlinear methods stability and performance are

analysed using powerful techniques including implementation considerations using digital computing means Other key features Covers the main types of AC motors including triphase multiphase and doubly fed induction motors wound rotor permanent magnet and interior PM synchronous motors Illustrates the usefulness of the advanced control methods via industrial applications including electric vehicles high speed trains steel mills and more Includes special focus on sensorless nonlinear observers adaptive and robust nonlinear controllers output feedback controllers fault detection and isolation algorithms and fault tolerant controllers This comprehensive volume provides researchers and designers and R D engineers with a single source reference on AC motor system drives in the automotive and transportation industry It will also appeal to advanced students in automatic control electrical power systems mechanical engineering and robotics as well as mechatronic process and applied control system engineers

Power Converters and AC Electrical Drives with Linear Neural Networks Maurizio Cirrincione, Marcello Pucci, Gianpaolo Vitale, 2017-12-19 The first book of its kind Power Converters and AC Electrical Drives with Linear Neural Networks systematically explores the application of neural networks in the field of power electronics with particular emphasis on the sensorless control of AC drives It presents the classical theory based on space vectors in identification discusses control of electrical drives and power converters and examines improvements that can be attained when using linear neural networks The book integrates power electronics and electrical drives with artificial neural networks ANN Organized into four parts it first deals with voltage source inverters and their control It then covers AC electrical drive control focusing on induction and permanent magnet synchronous motor drives The third part examines theoretical aspects of linear neural networks particularly the neural EXIN family The fourth part highlights original applications in electrical drives and power quality ranging from neural based parameter estimation and sensorless control to distributed generation systems from renewable sources and active power filters Simulation and experimental results are provided to validate the theories Written by experts in the field this state of the art book requires basic knowledge of electrical machines and power electronics as well as some familiarity with control systems signal processing linear algebra and numerical analysis Offering multiple paths through the material the text is suitable for undergraduate and postgraduate students theoreticians practicing engineers and researchers involved in applications of ANNs

Electromechanical Systems, Electric Machines, and Applied Mechatronics Sergey Edward Lyshevski, 2018-02-06 Recent trends in engineering show increased emphasis on integrated analysis design and control of advanced electromechanical systems and their scope continues to expand Mechatronics a breakthrough concept has evolved to attack integrate and solve a variety of emerging problems in engineering and there appears to be no end to its application It has become essential for all engineers to understand its basic theoretical standpoints and practical applications Electromechanical Systems Electric Machines and Applied Mechatronics presents a unique combination of traditional engineering topics and the latest technologies integrated to stimulate new advances in the analysis and design of state of the art electromechanical systems With a focus on numerical

and analytical methods the author develops the rigorous theory of electromechanical systems and helps build problem solving skills He also stresses simulation as a critical aspect of developing and prototyping advanced systems He uses the MATLABTM environment for his examples and includes a MATLABTM diskette with the book thus providing a solid introduction to this standard engineering tool Readable interesting and accessible *Electromechanical Systems Electric Machines and Applied Mechatronics* develops a thorough understanding of the integrated perspectives in the design and analysis of electromechanical systems It covers the basic concepts in mechatronics and with numerous worked examples prepares the reader to use the results in engineering practice Readers who master this book will know what they are doing why they are doing it and how to do it *Power Converter of Electric Machines, Renewable Energy Systems, and Transportation* Adolfo Dannier, Gianluca Brando, Marino Coppola, 2021-09-02 Power converters and electric machines represent essential components in all fields of electrical engineering In fact we are heading towards a future where energy will be more and more electrical electrical vehicles electrical motors renewables storage systems are now widespread The ongoing energy transition poses new challenges for interfacing and integrating different power systems The constraints of space weight reliability performance and autonomy for the electric system have increased the attention of scientific research in order to find more and more appropriate technological solutions In this context power converters and electric machines assume a key role in enabling higher performance of electrical power conversion Consequently the design and control of power converters and electric machines shall be developed accordingly to the requirements of the specific application thus leading to more specialized solutions with the aim of enhancing the reliability fault tolerance and flexibility of the next generation power systems **Induction Motor Control Design** Riccardo Marino, Patrizio Tomei, Cristiano M. Verrelli, 2010-08-20 This book provides the most important steps and concerns in the design of estimation and control algorithms for induction motors A single notation and modern nonlinear control terminology is used to make the book accessible although a more theoretical control viewpoint is also given Focusing on the induction motor with the concepts of stability and nonlinear control theory given in appendices this book covers speed sensorless control design of adaptive observers and parameter estimators a discussion of nonlinear adaptive controls containing parameter estimation algorithms and comparative simulations of different control algorithms The book sets out basic assumptions structural properties modelling state feedback control and estimation algorithms then moves to more complex output feedback control algorithms based on stator current measurements and modelling for speed sensorless control The induction motor exhibits many typical and unavoidable nonlinear features **Linear Electric Machines, Drives, and MAGLEVs Handbook** Ion Boldea, 2017-12-19 Based on author Ion Boldea's 40 years of experience and the latest research *Linear Electric Machines Drives and Maglevs Handbook* provides a practical and comprehensive resource on the steady improvement in this field The book presents in depth reviews of basic concepts and detailed explorations of complex subjects including classifications and

practical topologies with sample results based on an up to date survey of the field Packed with case studies this state of the art handbook covers topics such as modeling steady state and transients as well as control design and testing of linear machines and drives It includes discussion of types and applications from small compressors for refrigerators to MAGLEV transportation of linear electric machines Additional topics include low and high speed linear induction or synchronous motors with and without PMs with progressive or oscillatory linear motion from topologies through modeling design dynamics and control With a breadth and depth of coverage not found in currently available references this book includes formulas and methods that make it an authoritative and comprehensive resource for use in R D and testing of innovative solutions to new industrial challenges in linear electric motion energy automatic control

Manufacturing Technology, Electronics, Computer and Information Technology Applications Zhang Lin,Hong Ying Hu,Ya Jun Zhang,Jian Guo Qiao,Jia Min Xu,2014-11-27 Selected peer reviewed papers from the 2014 International Conference on Manufacturing Technology and Electronics Applications ICMTEA 2014 November 8 9 2014 Taiyuan Shanxi China

Power Quality in Power Systems and Electrical Machines Ewald F. Fuchs,Mohammad A. S. Masoum,2015-07-14 The second edition of this must have reference covers power quality issues in four parts including new discussions related to renewable energy systems The first part of the book provides background on causes effects standards and measurements of power quality and harmonics Once the basics are established the authors move on to harmonic modeling of power systems including components and apparatus electric machines The final part of the book is devoted to power quality mitigation approaches and devices and the fourth part extends the analysis to power quality solutions for renewable energy systems Throughout the book worked examples and exercises provide practical applications and tables charts and graphs offer useful data for the modeling and analysis of power quality issues Provides theoretical and practical insight into power quality problems of electric machines and systems 134 practical application example problems with solutions 125 problems at the end of chapters dealing with practical applications 924 references mostly journal articles and conference papers as well as national and international standards and guidelines

Nonlinear Control Algorithms for Electric Machines Praveen Vedagarbha,1997

Recent Advances in Electrical and Information Technologies for Sustainable Development Soumia El Hani,Mohamad Essaaidi,2019-02-08 The book includes the best extended papers which were selected from the 3rd International Conference of Electrical and Information Technologies ICEIT 2017 Morocco The book spans two inter related research domains which shaped modern societies solved many of their development problems and contributed to their unprecedented economic growth and social welfare Selected papers are based on original and high quality research They were peer reviewed by experts in the field They are grouped into five parts Part I deals with Power System and Electronics topics that include Power Electronics Energy Conversion Actuators Micro Nanotechnology etc Part II relates to Control Systems and their applications Part III concerns the topic of Information Technology that basically includes Smart Grid

Information Security Cloud Computing Distributed Big Data etc Part IV discusses Telecommunications and Vehicular Technologies topics that include Green Networking and Communications Wireless Ad hoc and Sensor Networks etc Part V covers Green Applications and Interdisciplinary topics that include intelligent and Green Technologies for Transportation Systems Smart Cities etc This book offers a good opportunity for young researchers novice scholars and whole academic sphere to explore new trends in Electrical and information Technologies **Conference Proceedings** IEEE Power Engineering Society. Winter Meeting,2000

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Table of Contents Nonlinear Control Of Electric Machinery

1. Understanding the eBook Nonlinear Control Of Electric Machinery
 - The Rise of Digital Reading Nonlinear Control Of Electric Machinery
 - Advantages of eBooks Over Traditional Books
2. Identifying Nonlinear Control Of Electric Machinery
 - 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 Nonlinear Control Of Electric Machinery
 - User-Friendly Interface
4. Exploring eBook Recommendations from Nonlinear Control Of Electric Machinery
 - Personalized Recommendations
 - Nonlinear Control Of Electric Machinery User Reviews and Ratings
 - Nonlinear Control Of Electric Machinery and Bestseller Lists
5. Accessing Nonlinear Control Of Electric Machinery Free and Paid eBooks

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

- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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