Preface

This book presents an innovative control system design methodology that is based on the latest research and development results at Sandia National Laboratories within the renewable energy electric power grid integration program. The inspiration for these research and development results are from three problems. The first problem is to find a unifying metric to compare the value of different energy sources to be integrated into the electric power grid such as coal-burning power plants, wind turbines, solar photovoltaics, etc., instead of the typical metric of costs/profits. The unifying metric of choice turns out to be exergy which is effectively negative entropy since price, in economic terms, has too many unaccounted for externalities. The second problem was to develop a new nonlinear control tool that applies power flow control, thermodynamics, and complex adaptive systems theory to the energy grid in a consistent way. The third problem is mathematically formulating how a person effectively navigates a time, spatially varying environment from a robotic engineer's point of view such that collective robotic theories can be used to create optimal individuals and high-performance teams of people. This problem is far from solved, however many of the basic concepts in this book are a result of how a person regulates power flows. These insights will be used in the future to account for the effects of individuals and groups of people that will be controlling and selling power into a distributed, decentralized electric power grid. In addition, these problems have several key concepts in common: exergy flow, limit cycles, and balance between competing power flows.

The main goal of the research effort was to develop a methodology that provides a unique set of criteria to design nonlinear controllers for nonlinear systems. This methodology addresses both stability and performance as well as seamlessly integrating information theory concepts instead of following the typical linear controller zero-sum design trade-off process between stability and performance. It works by combining concepts from thermodynamic exergy and entropy, Hamiltonian mechanics, Lyapunov's direct method and Lyapunov optimal analysis, electric AC power concepts, power flow analysis, and Fisher Information. The thermodynamic concepts are employed to allow the control design to be viewed as a power flow approach. This power flow approach balances power generation and power dissipation subject to the power storage (i.e., kinetic and potential energies) for a special class of dynamical systems called Hamiltonian natural systems and adiabatic irreversible work processes. This approach provides both necessary and sufficient conditions for stability while simultaneously allowing for performance specifications.

This book has been subdivided into three parts; theory, applications, and advanced concepts. In the first part (Chaps. 1–5), the necessary theoretical developments are presented that include: nonequilibrium thermodynamics, Hamiltonian mechanics, stability principles, and advanced control design concepts. In part two (Chaps. 6–13), the methodology is demonstrated through multiple case studies ranging from control design issues, collective plume tracing, nonlinear aeroelasticity and wind turbine control, fundamental power engineering, renewable energy microgrid design, robotic manipulator control, to satellite reorientation control. In part three, Chap. 14, advanced concepts are introduced that employ the fundamental theory, from part one as a foundation, and demonstrates how to extend it sustainability of self-organizing systems.

Research scientists, practicing engineers, applied mathematicians, physicists, and engineering students with a background in and basic understanding of thermodynamics, dynamics, and controls will be able to develop and apply this methodology to their particular problems. Considerable emphasis is placed on the necessary design steps for which the concepts are introduced and explained with numerous examples and a variety of case studies. The organization of the book makes it possible to be used as a first-level graduate course on nonlinear control design or as a reference or supplemental textbook for a special topic in support of a broader control theory course. In addition, the book has been developed in such a fashion that the interested reader, through self-study, could broaden their understanding of the analysis, design, and synthesis of nonlinear control systems.

Several distinctive features that are developed in this book are:

- Our approach provides both necessary and sufficient conditions for stability of a class of nonlinear systems while simultaneously allowing for performance specifications.
- Our approach provides seamless connections between information theory and nonlinear control by demonstrating the equivalence of physical and information exergies by applying nonlinear equilibrium thermodynamics, Hamiltonian mechanics, quantum mechanics, and Fisher Information.
- The material has been subdivided into three parts: theory, applications, and advanced concepts. This allows the reader to progressively move through the material, such as in a classroom environment or selectively investigate chapters most related to their own interests, working at their own pace. Many of the case studies are provided with explicit design steps to illustrate the ideas and principles behind the nonlinear power flow control methodology.
- Several of the case studies have been selected surrounding advanced and future control system designs and issues associated with the current integration of renewable energies (wind and solar) and interlaced with conventional energy sources and operations.

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