Microgrids and Other Local Area Power and Energy Systems

Describing the formation, integration, planning, design, and operation of microgrids, this book explains how local power and energy systems can address limitations in conventional electric power grids, and provides insights into the practical implementation needs and outcomes of microgrid technology.

Many aspects of microgrid design and applications are covered, including the main technologies involved in microgrids and other local area power and energy systems. The reliability and economic characteristics of microgrid system architecture, energy storage, and grid interaction are explored in depth.

Over 300 illustrations and real-world application examples make this a fully self-contained resource, ideal for graduate students and professionals in electrical, mechanical, and chemical engineering, and materials science.

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"Looking to the future of dispersed control implemented in localized power systems with diverse resources, architectures, and management, this book circulates correctly around the expanding capabilities and falling costs of power electronics. It comprehensively lays out techniques for conducting the key reliability, resiliency, and related economic analyses, neatly introduces the major generation and storage technologies, and finally tackles the challenges of system integration, control, and interconnection."

Chris Marnay, Lawrence Berkeley National Laboratory

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To our families

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Preface

It can be said that this book loosely originated at the University of Illinois at Urbana-Champaign where the three authors met during graduate studies under the advising of Professor Philip T. Krein. It was likely the combination of this enlightening environment and our combined perspectives from past industry experience that caused the three of us to gravitate toward studying microgrids. Although the concept of microgrids implied revisiting a ideas initially proposed by Thomas Edison, much of the technology had obviously changed since the late 1800s. Perhaps the most significant is that, power electronics now provides the ability to step-up or step-down dc voltage, a flexibility that Edison's concept lacked. Today, in modern large interconnected power grids, the need for integrating new technologies (such as renewable energy sources and energy storage) has also led to a search for new technological solutions and, in particular, modern microgrids have emerged. Still, during the first decade of the twenty-first century, when we were together at the University of Illinois, the concept of microgrids was not mainstream and the focus of most University power programs were staunchly divided between power systems and power electronics. Power systems studies tended to center their attention on large conventional interconnected power grids. Power electronics programs were mostly oriented to circuit topologies, devices, or control analysis. Microgrids represented, at the time, a bridge between these two large areas of study of power systems and power electronics in to a new research area that could be called power electronics systems. Hence, the study of microgrids and what we call in this book local area power and energy systems represented pioneering work, not only because it bridged power systems and power electronics, but because of the enormous potential applications for this technology and impact on society. For example, in the United States microgrids became a mainstream technology for improved power resilience to natural disasters after Superstorm Sandy affected New York City and the New Jersey Shore in late 2012, but this technological relevance of microgrids had already been identified by us in 2005 after studying the effects of Hurricane Katrina on critical power infrastructure.

After we graduated from the University of Illinois, the three of us eventually started careers in academia as faculty members at The University of Texas at Austin (Dr. Alexis Kwasinski), Michigan Technological University (Dr. Wayne Weaver), and Texas A&M University (Dr. Robert S. Balog). Microgrids formed a key research and instructional topic in the programs we developed at these universities, where we eventually were granted tenure. It was during the second half of our tenure evaluation periods that we

started working on this book, in part motivated by the need we identified in the literature for a book about microgrids that could also serve to connect with the existing literature that focused primarily on power systems or on power electronics. One challenge that we initially faced when trying to introduce students to the topic of microgrids was the lack of comprehensive reference literature on this topic that was appropriate for students. Existing books on power systems were of limited assistance because microgrids represent a system with considerable differences from conventional power grids. The problem persisted when we searched for a book that could be used not just as an introduction to the topic of microgrids but also for those continuing to work on the subject. This gap in the existing literature was an important motivation for this book.

This book is primarily intended for a graduate-level course on distributed generation or as a companion for researchers and practitioners in the field. There is an increased demand for courses and curriculum pertaining to distributed generation and microgrid systems, fueled by the increasing interest in environmentally friendly energy sources, improved reliability, resilience and availability, new electric energy utilization technologies, smart-grid development, and plug-in electric vehicles and other emerging technology areas. However, most existing books are written from a classical power system perspective, focused on renewable sources, or present only a cursory view too basic for a graduate-level course. One alternative is to resort to scientific journal and conference papers, but from a didactic perspective these publications are usually too specific and do not describe with sufficient detail the fundamental concepts on which they are based. One of the goals that we had in writing this book, then, was to alleviate the burden on instructors searching for content and, more importantly, to develop an integral framework to provide a sufficient cohesive discourse. As a result, this book contains all of the requisite background, technology, and theoretical concepts related to distributed generation systems with an orientation toward power electronics. It is also important to recognize that many of the topics discussed in this book are still the focus of research projects, so it is expected that a better future understanding of these topics will lead to alternative applications and designs. For this reason, a few of the topics are presented at an introductory level for research by providing sufficient information to study the related problems but without reaching the more advanced detailed discussion that is expected to significantly change in the near future as the result of ongoing research. In general, this book is aimed primarily at the graduate-level electrical engineering academic community, i.e., graduate students in graduate-level course sand researchers. However, we also tried to present topics so the book will be useful to practicing professional engineers in the power systems and power electronics areas. At a graduate level this book can be used in a graduate-level course that discusses advanced topics in power electronics, distributed generation, and/or smart grids. As a result, this book was written under the assumption that readers have sufficient background knowledge to understand technical discussions about microgrids at a graduate level. Necessary prerequisite knowledge in order to understand the topics discussed in this book includes undergraduate-level knowledge of power electronics, control systems, power systems, economics, and

probability and statistics. Some knowledge of basic concepts in mechanical and chemical sciences is also desirable.

Finally, we would like to express our gratitude to Doctor Sung Woo Bae, who assisted by converting class notes from the Distributed Generation Technologies course taught at The University of Texas at Austin that were in the form of slides into text to form the basis for Chapters 5 and 6. We would also like to thank Dr. Amir Toliyat, who helped improve Chapter 8 by proofreading it and suggesting some improvements. We are also grateful for the financial support provided by various industrial sponsors and the US National Science Foundation, the US Department of Energy, the Office of Naval Research, and the Qatar Foundation which helped us to develop our research programs.

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