Networked Microgrids

Discover scalable, dependable, and intelligent solutions to the challenges of integrating complex networked microgrids with this definitive guide to the development of cutting-edge power and data systems.

It includes:

- Advanced fault management control and optimization to enable enhanced microgrid penetration without compromising reliability.
- SDN-based architectures and techniques to enable secure, reliable and fault-tolerant algorithms for resilient networked systems.
- Reachability techniques to facilitate a deeper understanding of microgrid resilience in areas with high penetration of renewables.

Combining resilient control, fast programmable networking, reachability analysis, and cyberphysical security, this is essential reading for researchers, professional engineers, and graduate students interested in creating the next generation of data-intensive self-configurable networked microgrid systems, smart communities, and smart infrastructure.

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To Haizhen, William, Henry, and Benjamin

Contents

Preface and Acknowledgments

There is an increasing demand for highly reliable and sustainable power supplies under the fast development of smart and connected communities in recent years. Meanwhile, the global trend of urbanization has been posing significant challenges on the heavily loaded and aging power infrastructures in our cities. As predicted by the United Nations, a population increase of over one billion is expected to happen in urban areas in the next 15 years. Consequently, our existing power infrastructures, which are already operating close to physical limits, may not be sustainable to support the ever-growing demand of expanding cities and smart and connected communities. As an example, there was an outage on July 13, 2019, that left tens of thousands of customers in Midtown Manhattan and the Upper West Side of New York City in blackout. Most recently, tens of thousands of homes in California experienced two rounds of planned outages in an attempt to avoid wildfires during wind events.

Microgrids have proved to be a promising paradigm of electricity resiliency. They are promising to keep local community services up and running despite utility grid outages and weather events. The vision of this book is that networking community microgrids can achieve more resilience benefits and potentially transform today's community power infrastructures into tomorrow's autonomic networks and flexible services toward self-configuration, self-healing, self-optimizing, and self-protection against cyberattacks, high levels of distributed energy resource penetration, faults, and disastrous events.

This book summarizes some of my team's initial efforts in creating smart networked microgrids by introducing new technologies that enable software-defined, hardware-independent, and resilient microgrid functions. A few students and former students assisted me in writing this book. Yanyuan Qin contributed the software-defined networking part of Chapter 4. Dr. Yifan Zhou did meticulous work to improve Chapter 5. Wenfeng Wan, with Mikhail A. Bragin and Bing Yan, made major contributions to Chapter 6. For Chapter 7, Zimin Jiang worked hard to produce most of the simulation results, and Zefan Tang helped write the majority of the chapter. Lizhi Wang developed various figures in Chapters 2 and 4. Lingyu Ren and Yanyuan Qin produced the test results in Chapter 4. Yan Li produced some figures and results in Chapter 5 and part of those in Chapters 3 and 7 along with Yanyuan Qin. Saman Dadjo Tavakoli contributed Chapter 8, where a few figures were drawn by Jiangwei Wang. Fei Feng updated some results and figures in Chapters 3 and 7. Yifan Zhou, Zefan Tang, Wenfeng Wan, Lizhi Wang, Fei Feng, Zimin Jiang, and other team members at

Stony Brook University are enthusiastically performing a series of innovative topics in microgrids and networked microgrids. We will continue to bring in novel results and tools for our community.

I am grateful to various researchers and colleagues who collaborated with me in the journey of microgrid research. The author would like to thank his former advisors Professor Yutian Liu, Professor José R. Martí, and Professor Hermann W. Dommel for their consistent support. I would like to express my gratitude to Professor Peter B. Luh, Professor Bing Wang, Professor Jun Yan, Professor Guiling Wang, Joel Rinebold, Professor Peter Willett, Professor Yaakov Bar-Shalom, Professor Chongqing Kang, Professor Yilu Liu, Professor Petar M. Djurić, and Professor Mónica F. Bugallo. Working with the colleagues has enhanced my knowledge and expanded my vision in several perspectives. I would like to thank Professor Emmanouil Anagnostou and Professor John Chandy for their leadership and support in the past years. I would like to thank Professor Matthias Althoff and Professor Weidong Xiao for discussions and their friendship. Colleagues at Eversource Energy (formerly known as Northeast Utilities) David A. Ferrante, Joseph N. Debs, Kenneth Bowes, Rodrick Kalbfleisch, Diego Castillo, Samuel Woolard, Andrew Kasznay, Camilo Serna, and Christopher Leigh deserve big thanks for their valuable support and friendship.

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Notation

AC	alternating current
AFM	active fault management
AMI	advanced metering infrastructure
ComPF	compositional power flow
DAEs	differential-algebraic system of equations
DAPI	distributed averaging proportional-integral
DA-SLR	distributed and asynchronous surrogate Lagrangian relaxation
DC	direct current
DER	distributed energy resource
DFA	distributed formal analysis
DOE	Department of Energy
DQG	quasidiagonalized Geršgorin (DQG) theory
D-STATCOM	Distribution Static Synchronous Compensator
EMF	electromotive force
EMS	energy management system
FA	formal analysis
FRT	fault ride-through
HIL	hardware-in-the-loop
HTS	host tracking service
ID	identification
IoT	internet of Things
IP	internet protocol
LC	local controller
LFC	load frequency control
MAC	media access control
MIMO	multi-input multi-output
MIP	mixed-integer programming
microPMU	microphasor measurement unit
microRAS	microgrid remedial action scheme
NMs	networked microgrids
NMCC	networked microgrids coordination center
NSF	National Science Foundation
ODE	ordinary differential equation

OPF	optimal power flow
PAC	protection, automation, and control
PCC	point of common coupling
PLL	phase lock loop
PV	photovoltaic
PWM	pulse-width modulation
QoS	quality of service
QR	eigenvalue algorithm through QR decomposition
RGA	relative gain array
RTU	remote terminal unit
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
S&CC	smart and connected community
SDASD	software-defined active synchronous detection
SDN	software-defined networking
SD^2N	software-defined distribution network
SPM	smart programmable microgrid
SQP	sequential quadratic programming
SVD	singular value decomposition
TCP	transmission control protocol
UDN	urban distribution network
UDP	user datagram protocol
VM	virtual machine
VSG	virtual synchronous generator
VSI	voltage source inverter