Smart Grid

Networking, Data Management, and Business Models

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Preface

Electricity, a core service for many societal functions, reaches consumers via the electrical power grid. Since the mid-2000s, efforts in modernizing the electricity grid have led to a number of advances in the way power is generated, delivered, transmitted, stored, and consumed. New models of supply and demand brought in new business perspectives. Climate change and the drive toward low-carbon economies played a critical role in the advancement and adoption of electric vehicles. In the heart of this fast-phased evolution of energy and transportation sectors, information and communication technologies had the lion's share in transforming legacy systems into the so-called smart grid and smart cities. Power systems are becoming more manageable with a high volume of data flowing between grid operators and customers. The management of data that is large in volume, variety, and velocity has led to a whole new area of research in the past few years. Communication between loads and suppliers, high-resolution monitoring of substations, and energy trading communities are among the few of the advancements we have witnessed so far. In addition, coordinated electric vehicle charging and vehicle-to-grid power flow are emerging areas of research with high impact on future generations.

This book covers a broad range of emerging topics in communication infrastructures for the smart grid and electric vehicles, management of smart grid data, as well as business and pricing models for the power grid. This book aims to be a complementary reference for utility operators, telecom operators, communications engineers, power engineers, electric vehicle OEMs, electric vehicle service providers, university professors, researchers, and students who would like to grasp the advances in the smart grid and electric vehicle world. This book accommodates 16 book chapters authored by world-renowned experts, all presenting their views on smart grid communications and networks, data management, and business models. The chapters are organized in four sections.

Section I: Smart Grid Communications focuses on the latest advancements in smart grid communications, including cognitive radio-based solutions and software-defined networking approaches. This section consists of three chapters.

Chapter 1, authored by Dimitris Kogias, Gurkan Tuna, and Vehbi Cagri Gungor, discusses the potential use cases of cognitive radio in the smart grid along with research challenges that need to be addressed. Cognitive radio is a revolutionary technology that allows for opportunistic use of unused spectrum frequencies to increase communication capabilities and improve the overall system performance. Recently, the use of cognitive radio networking technology for the smart grid has been explored and promising results that can lead to remarkable advances have been observed.

Chapter 2, authored by Ozgur Ergul, Oktay Cetinkaya, and Ozgur Baris Akan, focuses on the recently proposed cognitive radio sensor network (CRSN) paradigm, which is a distributed network of sensors armed with cognitive radio capabilities that sense the environment and collaboratively communicate their measurements over available spectrum bands. The advantages and disadvantages of CRSNs are

discussed thoroughly. This chapter concludes with interesting future directions that pinpoint the open issues in this very active area of research.

Chapter 3, authored by Kemal Akkaya, A. Selcuk Uluagac, Abdullah Aydeger, and Apurva Mohan, is the last chapter of Section I. Software-defined networking (SDN) is a recently emerging networking paradigm that can provide excellent opportunities for reducing network management cost by integrating a software-based control that is flexible with software upgrades, flow-control, security patching, and quality of service. This chapter presents state-of-the-art research in adapting SDN for the existing needs of smart grid applications.

Section II: Smart Grid Security and Management consists of three chapters that address the cyber security of the smart grid along with management issues that arise around smart cities.

Chapter 4, authored by Guobin Xu, Paul Moulema, Linqang Ge, Houbing Song, and Wei Yu, systematically explores the space of attacks in the energy management process, including modules being attacked, attack venue, attack strength, and system knowledge, and develops a defense taxonomy to secure energy management with three orthogonal dimensions: methodology, sources, and domains. This chapter is a fundamental text treating security issues in the smart grid comprehensively.

Chapter 5, authored by Abdul Razaq, Huaglory Tianfield, Bernardi Pranggono, and Hong Yue, points out the need for developing a smart grid simulator and draws a road map for future research. A smart grid simulator needs to assess and evaluate the smart grid's reliability and cyber security across all the interdependent aspects such as power subsystems, automation, and communication networks while simulating the interactions among those different components. This chapter projects light on the smart grid simulator, which is a long-desired product by operators and researchers.

Chapter 6, authored by Stephen W. Turner and Suleyman Uludag, discusses in detail the challenges of positioning and managing the smart grid within the context of smart cities. This chapter prepares the readers for the following sections of this book where electric vehicles are discussed. The smart grid and electric vehicles are two interconnected infrastructures that are at the core of smart cities. This chapter explains the intertwined relationships among these with a language even a nonexpert reader can benefit from.

Section III: Demand Response Management and Business Models focuses on consumer and market aspects of the power grid. The five chapters included in this section explore the best ways of managing user demand along with optimal pricing schemes.

Chapter 7 is authored by Li Ping Qian, Yuan Wu, Ying Jun (Angela) Zhang, and Jianwei Huang. The authors present a real-time pricing scheme that aims to reduce the peak-to-average load ratio, while maximizing each user's payoff and retailer's profit. The formulated two-stage optimization problem considers user interactions at the lower scale and retailer pricing at the upper scale. Significant performance improvements have been suggested by the obtained results.

Chapter 8, authored by Zhi Chen and Lei Wu, proposes a sound real-time demand response management mechanism that can be embedded into smart meters and automatically executed for determining the optimal operation of appliances in the next 5-minute time interval while considering future electricity price uncertainties.

This chapter makes valuable contributions to the modeling of price-based demand response and scenario-based stochastic and robust optimization approaches.

Chapter 9, by Antimo Barbato, Cristina Rottondi, and Giacomo Verticale, provides an excellent overview of distributed and centralized demand side management. The authors present optimization approaches from both ends of the distributed and centralized spectrum and compare their performance in detail.

Chapter 10, by Melike Erol-Kantarci and Hussein T. Mouftah, has initially appeared in *Pervasive Communications Handbook* published by CRC Press in 2011. This chapter fills the gap in the area of low-carbon economies and the green smart grid and how these can be realized through pervasive management of demand.

Chapter 11, authored by Thomas H. Ortmeyer, is a reference chapter for every power and communications engineer who wishes to delve into the fundamentals of electricity distribution. This chapter provides an overview of distribution system characteristics that can impact the capability of the system to provide reliable power for electric vehicle charging stations.

Section IV: Microgrids, Electric Vehicles, and Energy Trading accommodates five chapters on cutting-edge research on microgrids, electric vehicles, and energy trading in the smart grid.

Chapter 12 is authored by Vincent François-Lavet, Quentin Gemine, Damien Ernst, and Raphael Fonteneau. The authors investigate how to optimally operate a microgrid given that supply and demand are known *a priori*. The authors' optimization model has been validated with real-life examples from Belgium and Spain.

Chapter 13, by Xavier Fernando, sets the stage for the final chapters of this book by giving a comprehensive review of the history and future of electric vehicles. The challenges of electrical vehicle charging along with the opportunities arising from utilizing their batteries as storage for blackouts are discussed thoroughly.

Chapter 14, authored by Christos Tsoleridis, Periklis Chatzimisios, and Panayiotis Fouliras, discusses the business and communication challenges behind V2G, which is electricity flowing from electric vehicle batteries toward the power grid. The authors provide a satisfactory list of open issues at the end of their chapter, which is an invaluable source for researchers who are seeking to advance the area.

Chapter 15, authored by Dhaou Said, Soumaya Cherkaoui, and Lyes Khoukhi, presents an optimization framework for electric vehicle charging that targets to minimize peak load on the distribution system. The proposed solution makes use of dynamic pricing of the smart grid and the obtained results suggest significant performance improvement.

Chapter 16, by Bhaskar Prasad Rimal, Ahmed Belgana, and Martin Maier, is the last chapter of this book. Energy trading is one of the leading-edge research topics in smart grid domain. The game-theoretic approach adopted in this chapter provides a real-time energy trading mechanism between multiple sources and multiple customers in an open energy market. The results suggest that noncooperative game models are promising and can optimize power losses among interconnected microsources.

This book contains 16 chapters grouped in four sections to make reading easy and pleasant for the audience of this book. Each chapter is authored by widely recognized

scholars in smart grid research. This book aims to be a handbook for researchers, academics, and practitioners, who desire to take active part in smart grid and smart cities research.

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Editors

Hussein T. Mouftah has earned DSc in EE from Laval University, Quebec City, Canada (1975), MSc in Computer Science from Alexandria University, Egypt (1972), and BSc in EE from Alexandria University, Egypt (1969). He is a distinguished university professor and Tier 1 Canada Research chair in wireless sensor networks at the School of Electrical Engineering and Computer Science of the University of Ottawa, Canada. He has been with the ECE (Electrical and Computer Engineering) Department at Queen's University (1979–2002), where he was prior to his departure as a full professor and the department associate head. He has six years of industrial experience mainly at Bell Northern Research of Ottawa (then known as Nortel Networks). He served as editor-in-chief of the *IEEE Communications Magazine* (1995–1997) and director of *IEEE ComSoc Magazines* (1998–1999), chair of the Awards Committee (2002–2003), director of Education (2006–2007), and member of the Board of Governors (1997–1999 and 2006–2007). He has been a distinguished speaker of the IEEE Communications Society (2000–2008). He is the author or coauthor of 10 books, 71 book chapters and more than 1400 technical papers, 14 patents, and 144 industrial reports. He is the joint holder of 19 Best Paper and/or Outstanding Paper Awards. He has received numerous prestigious awards, such as the 2014 Technical Achievement Award in wireless ad hoc and sensor networks of the IEEE ComSoc AHSN-TC, the EIC 2014 K. Y. Lo Medal, the 2007 Royal Society of Canada Thomas W. Eadie Medal, the 2007–2008 University of Ottawa Award for Excellence in Research, the 2008 ORION Leadership Award of Merit, the 2006 IEEE Canada McNaughton Gold Medal, the 2006 EIC Julian Smith Medal, the 2004 IEEE ComSoc Edwin Howard Armstrong Achievement Award, the 2004 George S. Glinski Award for Excellence in Research of the U of O Faculty of Engineering, the 1989 Engineering Medal for Research and Development of the Association of Professional Engineers of Ontario (PEO), and the Ontario Distinguished Researcher Award of the Ontario Innovation Trust (2002). Dr. Mouftah is a Fellow of the IEEE (1990), the Canadian Academy of Engineering (2003), the Engineering Institute of Canada (2005), and the Royal Society of Canada RSC Academy of Science (2008).

Melike Erol-Kantarci is an assistant professor at the Department of Electrical and Computer Engineering, Clarkson University, Potsdam, New York. She is the director of Networked Systems and Communications Research (NETCORE) Lab. Previously she was the coordinator of the Smart Grid Communications Lab and a postdoctoral fellow at the School of Electrical Engineering and Computer Science, University of Ottawa, Canada. She earned her PhD and MSc in computer engineering from Istanbul Technical University in 2009 and 2004, respectively. During her PhD studies, she was a Fulbright visiting researcher at the Computer Science Department of the University of California Los Angeles (UCLA). She earned her BSc from the Department of Control and Computer Engineering of the Istanbul Technical University in 2001. Dr. Erol-Kantarci received a Fulbright PhD Research Scholarship (2006) and the Siemens Excellence Award (2004), and she has won two Outstanding/Best Paper Awards. She is the coauthor of the article *Wireless Sensor Networks for Cost-Efficient Residential Energy Management in the Smart Grid* (*IEEE Transactions on Smart Grid*, vol. 2, no. 2, pp. 314–325, June 2011), which was listed in *IEEE ComSoc Best Readings on Smart Grid Communications*. Her main research interests are wireless sensor networks, smart grid, cyber-physical systems, electrification of transportation, underwater sensor networks, and wireless networks. She is a senior member of the IEEE and the former vice-chair for Women in Engineering (WIE) at the IEEE Ottawa Section. She is currently the vice-chair of Green Smart Grid Communications special interest group of IEEE Technical Committee on Green Communications and Computing.

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