Smart Grid Communications and Networking

The smart grid will transform the way power is delivered, consumed and accounted for. Adding intelligence through the newly networked grid will increase reliability and power quality, improve responsiveness, increase efficiency and provide a platform for new applications. This one-stop reference covers the state-of-the-art theory, key strategies, protocols, applications, deployment aspects and experimental studies of communication and networking technologies for the smart grid. Throughout the book's 20 chapters, a team of expert authors cover topics ranging from architectures and models through to integration of plug-in hybrid vehicles and security. Essential information is provided for researchers to make progress in the field and to allow power systems engineers to optimize communication systems for the smart grid.

Ekram Hossain is a Professor in the Department of Electrical and Computer Engineering at the University of Manitoba, Canada, where his current research interests lie in the design, analysis and optimization of wireless/mobile communications networks, smart grid communications, and cognitive and green radio systems. He has received several awards including the University of Manitoba Merit Award in 2010 (for Research and Scholarly Activities) and the 2011 IEEE Communications Society Fred W. Ellersick Prize Paper Award.

Zhu Han is an Assistant Professor in the Electrical and Computer Engineering Department at the University of Houston, Texas. He received his Ph.D. in electrical engineering from the University of Maryland, College Park, in 2003 and worked for 2 years in industry as an R&D Engineer for JDSD. He is a recipient of the NSF CAREER Award (2010) and the IEEE Communications Society Fred W. Ellersick Prize Paper Award.

H. Vincent Poor is the Michael Henry Strater University Professor at Princeton University, New Jersey, where he is also Dean of the School of Engineering and Applied Science. He is a Fellow of the IEEE, and is a member of the US National Academy of Engineering and of the US National Academy of Sciences. He is also a Fellow of the American Academy of Arts and Sciences, an International Fellow of the Royal Academy of Engineering, and a former Guggenheim Fellow. Recent recognition of his work includes the 2009 Edwin Howard Armstrong Award of the IEEE Communications Society, the 2010 IET Ambrose Fleming Medal, the 2011 IEEE Eric E. Sumner Award, and an honorary doctorate from the University of Edinburgh.

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

"… an invaluable resource to engineers involved in the design of smart grid … this book will become an essential reference in the literature of smart grids and smart infrastructures."

Alberto Leon-Garcia, Univeristy of Toronto

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Smart Grid Communications and Networking

EKRAM HOSSAIN
University of Manitoba, Canada

ZHU HAN
University of Houston, Texas

H. VINCENT POOR
Princeton University, New Jersey

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Mexico City

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9781107014138

First published 2012

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data
Smart grid communications and networking / [edited by] Ekram Hossain, Zhu Han, H. Vincent Poor.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-107-01413-8 (hardback)
1. Smart power grids. I. Hossain, Ekram, 1971– II. Han, Zhu, 1974– III. Poor, H. Vincent.
TK3105.S488 2012
621.310285′46–dc23 2012008157

ISBN 978-1-107-01413-8 Hardback

**For
our families**

Contents

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Contributors

Mahnoosh Alizadeh
University of California Davis, USA

Jesus Alonso-Zarate
CTTC, Barcelona, Spain

Tamer Başar
University of Illinois at Urbana-Champaign, USA

Sara Bavarian
The University of British Columbia, Canada

Robin Berthier
University of Illinois at Urbana-Champaign, USA

Rakesh B. Bobba
University of Illinois at Urbana-Champaign, USA

Nicola Bui
University of Padova, Italy

Karen Butler-Purry
Texas A&M University, USA

Paolo Casari
University of Padova, Italy

Angelo P. Castellani
University of Padova, Italy

Dae-Hyun Choi
Texas A&M University, USA

György Dán
KTH Royal Institute of Technology, Sweden

Yi Deng
Virginia Polytechnic Institute and State University, USA

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Mischa Dohler
CTTC, Barcelona, Spain

Nada Golmie
NIST, USA

David Gregoratti
CTTC, Barcelona, Spain

David Griffith
NIST, USA

Vehbi Cagri Gungor
Bahcesehir University, Turkey

Gerhard P. Hancke Jr
Royal Holloway University of London, UK

Gerhard P. Hancke
University of Pretoria, South Africa

Erich Heine
University of Illinois at Urbana-Champaign, USA

Ekram Hossain
University of Manitoba, Canada

Rose Qingyang Hu
Utah State University, USA

Cunqing Hua
Zhejiang University, P. R. China

Jianwei Huang
The Chinese University of Hong Kong, Hong Kong, China

Soummya Kar
Carnegie Mellon University, USA

Nipendra Kayastha
Nanyang Technological University, Singapore

Himanshu Khurana
Honeywell Research Labs, USA

Deepa Kundur
Texas A&M University, USA

Lutz Lampe
The University of British Columbia, Canada

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Husheng Li
University of Tennessee, USA

Victor O. K. Li
University of Hong Kong, Hong Kong, China

Hua Lin
Virginia Polytechnic Institute and State University, USA

Salman Mashayehk
Texas A&M University, USA

Javier Matamoros
CTTC, Barcelona, Spain

Amir-Hamed Mohsenian-Rad
Texas Tech University, USA

Dusit Niyato
Nanyang Technological University, Singapore

Arun G. Phadke
Virginia Polytechnic Institute and State University, USA

H. Vincent Poor
Princeton University, USA

Michele Rossi
University of Padova, Italy

Dilan Sahin
Bahcesehir University, Turkey

Pedram Samadi
The University of British Columbia, Canada

Henrik Sandberg
KTH Royal Institute of Technology, Sweden

William H. Sanders
University of Illinois at Urbana-Champaign, USA

Anna Scaglione
University of California Davis, USA

Robert Schober
The University of British Columbia, Canada

Sandeep Shukla
Virginia Polytechnic Institute and State University, USA

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

Kin Cheong Sou
KTH Royal Institute of Technology, Sweden

Michael Souryal
NIST, USA

Ali Tajer
Princeton University, USA

James S. Thorp
Virginia Polytechnic Institute and State University, USA

Yi Qian
University of Nebraska-Lincoln, USA

Lorenzo Vangelista
University of Padova, Italy

Ping Wang
Nanyang Technological University, Singapore

Zhifang Wang
University of California Davis, USA

Vincent W. S. Wong
The University of British Columbia, Canada

Chenye Wu
Tsinghua University, China

Le Xie
Texas A&M University, USA

Guang-Hua Yang
University of Hong Kong, Hong Kong, China

Tim Yardley
University of Illinois at Urbana-Champaign, USA

Rong Zheng
The University of Houston, USA

Quanyan Zhu
University of Illinois at Urbana-Champaign, USA

Michele Zorzi
University of Padova, Italy

Takis Zourntos
Texas A&M University, USA

Preface

A brief journey through 'Smart Grid Communications and Networking'

A power grid consists of two major parts: the transmission and distribution systems. The transmission system refers to the high-voltage network infrastructure that connects the power generation facilities with the various distribution points. At the distribution points, the electrical carrier is converted to medium and low-voltage signals for the distribution systems that connect the customers. The smart power grid (or *smart grid* in short) refers to the next-generation electrical power grid that aims to provide reliable, efficient, secure, and quality energy generation/distribution/consumption using modern information, communications, and electronics technology. The smart grid will introduce a distributed and user-centric system that will incorporate end-consumers into its decision processes to provide a cost-effective and reliable energy supply. The modern communication infrastructure will play a vital role in managing, controlling, and optimizing different devices and systems in smart grids. Information and communication technologies are at the core of the smart grid vision as they will provide the power grid with the capability to support two-way energy and information flow, isolate and restore power outages more quickly, facilitate the integration of renewable energy sources into the grid and empower the consumer with tools for optimizing their energy consumption.

From an architectural perspective, a smart grid is comprised of three high-level layers: the physical power layer (transmission and distribution), the data transport and control layer (communication and control), and the application layer (applications and services). Each of these high-level layers breaks down further into sub-layers and more detailed market segments. Unlike its predecessor (i.e., the existing electrical power grid), smart grid will use two-way data communication technologies to integrate the utility control system with end-users and consumers, so that intelligent power generation, control, and consumption can be achieved. Moreover, smart grid will allow active participation of users by providing user information related to demand and fault reporting. Many standard bodies and organizations throughout the world are working towards this vision of smart grid. Among many, the Electrical Power Research Institute (EPRI), the National Institute of Standards and Technology (NIST), and European Commission Research (ECR) are working towards developing the most comprehensive frameworks, communication specifications, standards, and roadmaps for the smart grid. However, many issues such as cost, interoperability, cyber and physical security, lack of communication and architectural standards, etc., need to be addressed. Developing the smart grid has become an urgent global priority as its economic, environmental, and societal benefits will be enjoyed by future generations.

The objective of this book is to provide a useful background on advanced data communication and networking mechanisms, models for networked control, and security mechanisms for the smart grid. This book consists of chapters covering different aspects of data communications and networking in the smart grid that include the following: communications architectures and models for smart grid for advanced metering infrastructure (AMI), networked control, demand-side management (DSM), distributed energy resource (DER) management; physical communications, detection, estimation, and access design for smart grid; smart grid and area networks such as home-area networks (HANs), neighbourhood-area networks (NANs), wide-area networks (WANs), wide-area measurement systems (WAMSs); sensor and actuator networks (SANETs) for the smart grid and the related protocol design issues; security in communications infrastructure for the smart grid; and the ongoing projects and field-trials on the smart grid.

This book contains 20 chapters which are organized into six parts. A brief account of each chapter in each of these parts is given next.

Part I: Communication architectures and models for smart grid

A smart grid is a visionary user-centric system that will elevate the conventional power grid system to one that functions more cooperatively, responsively, and economically. In addition to the incumbent function of delivering electricity from suppliers to consumers, smart grids will also provide information and intelligence to the power grid to enable grid automation, active operation, and efficient demand response. A reliable and efficient communication and networking infrastructure will connect the functional elements within the smart grid.

In *Chapter 1*, Kayastha *et al.* describe the conceptual model for a smart grid adopted by NIST, and describe the interactions among its different domains (e.g., generation, transmission, distribution, customer, service provider, operations, market). In this context, the authors highlight the role and importance of smart grid communications and networking infrastructures, and present an overview of a hierarchical communication infrastructure which spans across the different domains in a smart grid. Such an infrastructure, which is also termed an AMI, comprises many systems and subsystems such as HANs, SANETs, NANs, and WANs. The authors also briefly describe the GridWise Architecture Council (GWAC) framework for interoperability in the integrated smart grid communications infrastructure. In addition, security and privacy issues related to the communications infrastructures in the smart grid are also reviewed.

In *Chapter 2*, Scaglione, Wang, and Alizadeh provide a brief overview of the classical issues of network control and how they relate to the challenges of creating a new architectural model for managing energy distribution in a smart grid that relies on real-time, dependable information gathering and decisions. The authors discuss the important questions that exist in tightening the networked control at the core of the network and at its edges and why these are important parts to unleash innovations in the smart grid.

They discuss how wide-area measurement systems connecting phasor measurement units (PMUs) through novel sensor networking paradigms can help increase the situation awareness in the smart grid. The authors also review the supervisory control and data acquisition (SCADA) model which is currently used for grid monitoring and control. At the edge, the emerging smart metering infrastructure today offers only a glimpse of the possible advantages of having broad consumer participation. The opportunity is to tighten the control of the demand via real-time load scheduling. The authors discuss what are reasonable models for demand and response systems, also referred to as DSM systems, that proactively control smart loads, focusing on the specific example of an electric vehicle, as a compelling case to target for the study of load scheduling.

In *Chapter 3*, Samadi *et al.* present a number of methods for DSM based on smart pricing to improve the efficiency of traditional power grids. Two different objectives for such algorithms are: reducing power consumption and shifting (or scheduling) power consumption. Energy-consumption scheduling can reduce the peak-to-average ratio (PAR) of power consumption as well as minimize the total energy cost in the system. For users, another objective could be to minimize jointly the energy cost and waiting time. The authors consider these design objectives for DSM and present optimization and game-theoretic models to solve the DSM problem. The concept of utility functions is used to model different objectives of users.

In *Chapter 4*, Wu, Mohsenian-Rad, and Huang provide an introduction to vehicle-to-grid (V2G) systems and highlight the role of a reliable and secure communication and networking infrastructure for such systems in the future smart grid. A V2G system can inject power into the grid when required through discharging the batteries of plug-in electric vehicles (PHEVs). Such a system can improve the PAR in the system through a coordinated charging and discharging mechanism for the PHEVs. Also, the V2G power storage mechanism can facilitate integration of renewable energy (RE) sources into the smart grid. In addition, a V2G system can help to regulate frequency and voltage in a power grid. All of these services, which are referred to as ancillary services, can be offered to the power grid efficiently through an advanced communication and networking infrastructure. The authors briefly describe several technologies for V2G system communications which include broadband power-line communication (PLC), ZigBee, Z-Wave, cognitive radio, and cellular wireless technologies. The details of these technologies are discussed in Part II of the book.

Part II: Physical data communications, access, detection, and estimation techniques for smart grid

Different physical data communication technologies for the smart grid will empower the legacy power grid with the capability to support two-way energy and information flow. These technologies will facilitate integration of renewable energy sources into the grid, and empower the consumers with tools to optimize energy consumption. The smart grid will rely on several existing and future wired and wireless communications technologies (e.g., PLC, cellular network, IP networks, ZigBee, Wi-Fi, WiMAX, etc.). Also, advanced techniques for power-system state estimation and data processing (e.g., bad-data detection) will be required for smart grids.

In *Chapter 5*, Bavarian and Lampe provide an exposition on the different communications and access technologies and their applications in smart grid communications. Different wired communications technologies including power-line and optical-fibre technologies, and wireless technologies including cellular, satellite, wireless mesh, and wireless personal-area networking technologies are reviewed. Broadband and narrowband power-line communications technologies and the related standards (e.g., IEEE 1901, ITU-T G.9960/61, HomePlug) are discussed. Among the wireless technologies, the authors discuss the ZigBee, Wi-Fi, WiMAX, 3GPP LTE, and IEEE 802.22 standards. To this end, the authors also review networking solutions such as Internet and IP-based networks, private networks, wireless sensor and machine-to-machine (M2M) communication networks for smart grids.

In *Chapter 6*, Alonso-Zarate *et al.* review the emerging paradigm of M2M communications, including its definition, historical developments, design drivers, and the status-quo of its standardization efforts. The authors discuss in detail the applicability of the M2M communications to the smart grid and identify open challenges for a symbiotic development of both M2M and smart grid technologies. Different M2M communications technologies including cabled technologies (e.g., PLC, Ethernet), low-power wireless technologies such as ZigBee, Wi-Fi, 6LoWPAN (which are referred to as capillary M2M technologies), and hybrid M2M technologies are discussed. The authors argue that the cellular M2M communications technologies are suitable for smart grid applications such as wide-area situational awareness, interconnection of distributed energy resources, and distribution automation in the transmission and distribution networks. Also, cellular M2M is a technology enabler to build the AMI, and to realize the concept of direct load control (DLC) where intelligent devices can automatically schedule their power loads.

In *Chapter 7*, Xie *et al.* focus on the problem of fast and robust state-estimation techniques for wide-area monitoring, control, and protection in the smart grid. One essential functionality in state estimation is to detect, identify, and eliminate measurement errors, which arise due to the existence of large measurement bias, drifts, or wrong connections. This functionality is referred to as ‘bad-data processing’, which consists of two steps: bad-data detection and identification. Generally, a chi-square test is used for bad-data detection, and then a normalized residual test is used for bad-data identification. The authors review the state-of-the-art of bad-data processing techniques and present a distributed approach for bad-data detection. The performance of the proposed approach is observed by simulations using the IEEE 14-bus system. The information exchange and communication requirements for the proposed approach are also discussed.

In *Chapter 8*, Tajer, Kar, and Poor also deal with the problem of distributed power-system state estimation taking into account the uncertainties in the underlying physical and sensing models as well as the rapidly varying dynamics of the system. The authors define a learning-based framework for adaptive and distributed power-state estimation. They model the smart grid as a collection of multiple overlapping distributed subnetworks (or clusters) covering the entire network. The subnetworks share their estimates of network state with a central decision-maker entity (central estimator) through a backbone communication network. Then the central estimator combines the local state estimates to obtain the global state of the network. The estimation performance at the central estimator, as well as the estimation quality in each cluster, are modelled analytically using cost functions.

Part III: Smart grid and wide-area networks

Advanced data communication and networking techniques will play a key role in the successful development of the emerging smart grid system. The communication network in the smart grid must be able to support all aspects of generation, transmission, distribution, as well as the requirements of users and utility service providers. The data communication network in the smart grid will be responsible for sensing (i.e., gathering real-time measurements from various locations of the power grid through a WAMS), communication (i.e., bidirectional data exchange between smart meters and control centres), and control (i.e., delivery of control messages to ensure optimal, reliable, and resilient operation of the grid and its subsystems).

In *Chapter 9*, Deng *et al.* focus on the performance evaluation of network architectures and protocols for WAMS applications in the smart grid. The authors review the WAMS architecture (software and hardware) and the different components of WAMS, namely, the PMUs, regional phasor data concentrators (PDCs), centralized super-phasor data concentrator (SPDC), and hierarchically organized communication networks. A WAMS uses a multi-level hierarchical communication network with reliability, real-time responsiveness, scalability, and reliability, to integrate all these components together. The applications of WAMS for power-system monitoring, protection, and control are discussed in detail. A simulation platform based on the OPNET Modeler is designed for a realistic communication system of WAMS and simulation results are obtained for various control, monitoring, and hybrid WAMS applications.

In *Chapter 10*, Griffith, Souryal, and Golmie focus on the use of wireless networks to support the communications quality-of-service (QoS) and traffic requirements of different smart grid applications. These applications include firmware/program update (FPU), field distribution automation maintenance-centralized control (FDAMC) for communications between the distribution management system and various field devices, PHEV messaging, customer information/messaging (CMSG), and meter reading. The QoS requirements (e.g., latency and reliability) and the traffic characteristics of these applications, and also the message flows among the various actors for these applications and the resulting network topologies are discussed. The key factors such as the choice of radio spectrum, wireless channel propagation characteristics, wireless link coverage, and network capacity, resilience and security, which need to be considered for the deployment of wireless networks, are described. In this context, performance metrics such as coverage, capacity, reliability, and latency, which can be used to evaluate different wireless network alternatives, are also discussed.

Part IV: Sensor and actuator networks for smart grid

In a smart grid, wireless SANETs will be deployed in generation systems, transmission and distribution systems, and consumers' premises to monitor and control the functioning of the grid. The existing and potential applications of SANETs in the smart grid include advanced metering, fault diagnosis, demand response and dynamic pricing, energy management, etc. SANETs will be an integral component in future generation smart grids. However, the existing communication protocols for SANETs may need to be modified/optimized taking into consideration the smart grid application requirements.

In *Chapter 11*, Sahin *et al.* present the potential applications of wireless sensor networks (WSNs) in the smart grid and the related technical challenges. In particular, WSN-based applications have been described for power generation systems, transmission and distribution networks, and consumer facilities. For WSN-based smart grid applications, a number of research challenges exist which involve power, data, and resource management in sensors, interoperability among WSN protocols, QoS provisioning in the network, and system integration.

In *Chapter 12*, Zheng and Hua focus on the sensor technologies and communication protocols for sensor networks in the smart grid. The authors review major types of sensors which are categorized into metering and power-quality sensors and power-system status and health-monitoring sensors. In this context, different sensing principles, which are used to convert the physical parameters into electronic signals, are reviewed. The authors discuss the issues related to designing medium access control (MAC), routing, and transport protocols for WSNs in the smart grid. A brief survey on the existing protocols for general WSNs, along with a qualitative comparison among the different protocols, are also provided. The authors point out that designing sensor networking protocols for the smart grid is challenging due to the unique features of such systems; for example, the complex and heterogeneous nature of the environment, dynamic nature of the system, reliability, availability, and diverse QoS requirements, energy and cost-efficiency, and scalability and security issues.

In *Chapter 13*, Li and Yang focus on addressing the major design challenges of SANETs in smart grids as mentioned before. The authors propose mechanisms such as pervasive service-oriented networking, context-aware intelligent control, compressive sensing, and advanced device technologies (e.g., with low-power, modular, and compact design and power-harvesting mechanisms) to address the challenges. To this end, the effectiveness of the proposed mechanisms is demonstrated with a case study of a home energy-management system (HEMS).

In *Chapter 14*, Bui *et al.* focus on the implementation and performance evaluation of WSN protocols for smart grid applications in a test-bed built from off-the-shelf wireless sensors. In particular, the authors consider the protocol stack of the 'Internet of things' with IEEE 802.15.4 protocols at the physical (PHY) and MAC layers, 6LoWPAN (IPv6 over low-power wireless personal-area networks) at the routing layer, and CoAP (Constrained Application Protocol) at the application/session layer. The implementation of the test-bed is discussed along with the different optimization techniques used for the network and software implementations. The experimental results for the different layers of the protocol stack are presented. The authors conclude that WSN solutions based on the ‘Internet of things’ protocol stack are feasible to be integrated with the smart grid.

Part V: Security in smart grid communications and networking

Although the communication infrastructure can considerably improve the efficiency of the power system, it brings significant vulnerability since malicious users can attack the communication system and thus cause various damages to the smart grid, or even result in a large-area blackout. Hence, security is of high priority in the study of smart grids and has attracted substantial attention in industry and academia. We have five chapters which discuss the security issues in the smart grid from different perspectives.

In *Chapter 15*, Kundur *et al.* present a framework for cyber-attack impact analysis in the smart grid. First, background is provided to motivate and introduce fundamental research and development questions on cyber-attack impact analysis. Second, a graph-theoretic dynamical system approach is employed to model the interactions between the cyber and electricity networks in the model synthesis stage. Finally, a test case study is presented to demonstrate the potential for modelling.

In *Chapter 16*, Li proposes a jamming-based attack scheme for manipulating the power market in the smart grid. By intelligently blocking and releasing the information in the power market via jamming the wireless communications, malicious jammers/attackers can manipulate the power price, thus making profit for themselves and causing damage to the power grid. To combat this attack, random frequency hopping can be employed for communication, and a random backoff method is proposed for load adjustment in order to avoid the impulsive impact on the market price and power load due to jamming.

In *Chapter 17*, Dán, Sou, and Sandberg study bad-data injection attacks on state estimation in the smart grid using SCADA systems. State estimation is used to estimate the complete physical state of the power system, and bad-data detection is used to identify faulty equipment and corrupted measurement data. A stealth attack against bad-data detection is investigated, and several algorithms are used to protect the power system against this attack. A realistic model is added for communication of the supervisory control and data acquisition systems. Some new protection mechanisms are also presented.

In *Chapter 18*, Zhu and Başar describe a cross-layer architecture to address security issues in the smart grid. The tradeoff between information assurance and the physical layer system performance is investigated by three security issues at different layers: the resilient control design problem at the physical power plant, the data-routing problem at the network and communication layer, and the information security management at the application layers. The proposed hierarchical model extends the open system interconnection (OSI) and Purdue Reference models for their integration into smart grids.

In *Chapter 19*, Berthier *et al.* discuss an application-driven design approach that builds the large cyber security toolset. A key element is careful enumeration of the control-system-specific aspects of each system and an integrated study of these aspects, cyber security properties, and solutions. Specifically, the following topics are discussed

Cambridge University Press
978-1-107-01413-8 - Smart Grid Communications and Networking
Ekram Hossain, Zhu Han and H. Vincent Poor
Frontmatter
More information

in detail: intrusion detection for advanced metering infrastructure, converged networks for supervisory control and data acquisition, and design principles for authentication of SCADA protocols.

Part VI: Field trials and deployments

The relevance of smart grid is reflected by the increasing number of national and international projects on this topic as well as new initiatives by standardization bodies and organizations such as NIST, EPRI, ECR, and the IEEE. There have been several smart grid field trials in the last few years.

In *Chapter 20*, Hu and Qian provide an overview of several smart grid field trials which are divided into three categories: smart power grids, smart electricity systems, and smart customers. The first category includes the Jeju smart grid testbed in Korea, the advanced distribution system (ADS) programme in Ontario, Canada, and the SmartHouse project in Europe. The second category includes an intelligent protection relay system for smart grids. The third category includes several dynamic pricing schemes. The authors summarize the lessons learned from these pilot projects.