

Preface

In its Framework and Roadmap for Smart Grid Interoperability Standards, the US National Institute of Standards and Technology declares that a *twenty-first-century clean energy economy demands a twenty-first-century electric grid*.¹ The start of the twenty-first century marked the acceleration of the Smart Grid evolution. The goals of this evolution are broad, including the promotion of widespread and distributed deployment of renewable energy sources, increased energy efficiency, peak power reduction, automated demand response, improved reliability, lower energy delivery costs, and consumer participation in energy management. This evolution will touch each and every aspect of the electric power grid, a system that has changed little since its inception at the end of the nineteenth century. Realizing the goals of the Smart Grid evolution will require modernization of grid components, introduction of new control and monitoring technologies, and ongoing research and development of new technologies.

The “intelligence” of the Smart Grid relies upon the real-time exchange of measurement and control data among a vast web of devices installed in homes and businesses, within the distribution and transmission grids, and at substations, control centers, generation stations, and other facilities. Thus, a high-performance, reliable, secure, and scalable communication network is an integral part of the Smart Grid evolution.

However, the communication networks of many utilities today are ill-equipped to meet the challenges created by the Smart Grid evolution. These communication networks are largely purpose-built for the support of individual applications: separate networks for Supervisory Control and Data Acquisition (SCADA), for video surveillance, for Land Mobile Radio backhaul, and so on. These networks rely heavily on circuit-based transport technologies. The ever-expanding growth of network endpoints and applications as Smart Grid expands makes these current

¹National Institute of Standards and Technology, *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0*, NIST Publication 1108R2, U. S. Department of Commerce, February 2012.

practices untenable. A new, integrated network architecture is required, one that will carry traffic from all applications while meeting their disparate reliability, security, and performance requirements.

This book is a contribution to this growing body of knowledge. It is based both on our research into Smart Grid communications and on the consulting services we have provided electric power companies on transforming their existing communication networks to meet the challenges of Smart Grid evolution.

This book will be of interest to those engaged in the planning, deployment, engineering, operation, and regulation of Smart Grids, including strategists, planners, utility practitioners, communication network technology providers, communication network service providers, Smart Grid product vendors, regulators, and academics. This book will also be a resource for upper-level undergraduate and graduate courses covering Smart Grids.

We have taken an application-centric approach to the development of the Smart Grid communication architecture and network transformation based on that architecture. Therefore, a significant part of this book is devoted to describing the evolving Smart Grid applications such as Advanced Metering Infrastructure (AMI), distribution automation (DA), and traditional utility applications like SCADA.

We begin in Chap. 1 with characterizing the Smart Grid in the broadest sense. The electric power grid consists of power plants of bulk electric energy generation connected to a system of high-voltage transmission lines to deliver power to consumers through electric distribution systems. Communication networks have been used for grid monitoring in the latter part of the twentieth century but were limited to the substation-based SCADA and teleprotection systems. The need for clean energy with large-scale deployment of renewable sources of energy, advantages of peak power reduction for environmental and economic reasons, grid modernization, and consumer participation in energy management are some of the motivations for the evolution of Smart Grid. While Smart Grid is a natural evolution of the electric power grid, the evolution has taken a sense of urgency in the last decade.

Topics in power systems and grid operations relevant to this book are presented in Chap. 2 for the benefit of the readers with little background in power systems. After presenting the definitions of basic electric quantities like power and energy, a quick overview of alternate current systems and phasors is presented. Elements of power generation, transmission, and distribution systems are briefly described to provide background relevant to this book.

In Chap. 3, topics in communication networks relevant to this book are presented for the benefit of the readers with little background in networking. After a brief presentation of the data communication network architecture framework of the Open System Interconnection (OSI) architecture, networking layers pertinent to Smart Grid network are presented in more detail. Introduction to many wireless and wireline technologies is included. Since IP will be the network protocol of choice for the evolving smart networks, relevant IP networking features are described in more detail. Multiprotocol Label Switching (MPLS) technology is also included in this review since MPLS provides many important features needed in the Smart Grid

communication network, in addition to supporting utility applications that cannot be carried over an IP-only network.

Before the Smart Grid evolution began, networking for utility operations was generally limited to applications such as SCADA and teleprotection. Utility mobile workforce personnel use communication networks for their operations – mostly for push-to-talk voice communications. Some utilities have deployed network video surveillance with closed circuit television (CCTV) cameras. All these applications will continue to be supported in the Smart Grid network. In Chap. 4, these applications and their communication network requirements, networking protocols, and networking technologies are presented.

In Chap. 5, we present a comprehensive description of many of the new utility applications that can be attributed to the Smart Grid evolution. In addition to presenting their communication network requirements, we briefly discuss network protocols and network technology options for some of these applications. Applications included in this chapter are AMI, DA, distributed generation (DG), distributed storage, electric vehicles (EVs), microgrids, home area networks, retail energy markets, automated demand response, wide area situational awareness and synchrophasors, flexible AC transmission system, and dynamic line rating (DLR). Contributions of the application of Chaps. 4 and 5 to one or more of the four broad characteristics of the Smart Grid are summarized in a table at the end of this chapter.

In Chap. 6, the Smart Grid communication network architecture is developed. A core-edge network architecture is well suited for the Smart Grid network with many utility endpoints communicating with the application endpoints located in the utility data and control center (DCC). The concept of the wide area network (WAN) is formalized for the Smart Grid network as an interconnection of aggregation routers – called WAN routers. Other utility endpoints connect to the WAN at the WAN routers over access networks – called field area networks (FANs) in the utility community. While IP will be the overall network protocol, the architecture will support legacy applications and protocols for a period of time as desired by a utility. In addition to the physical network architecture, the logical network architecture is described with the use of many examples.

At the outset, it is important to understand that the networking requirements for a utility network are different in many aspects compared to those for a network service provider (NSP) network used for data services offered to its customers as well as for data networks in most enterprises. The NSP networks are primarily designed to support their customers' multimedia applications, while the Smart Grid network must support mission-critical applications such as SCADA, teleprotection, DA, and synchrophasors. Most enterprise data network requirements on reliability, security, and performance are less stringent than those of Smart Grid networks. Therefore, the network design paradigm for Smart Grid networks is different in many respects from that of the more established data network design practices. Chapter 7 begins with the characterization of Smart Grid logical connectivity and network traffic that are the inputs to network design. Design considerations are provided for the support of the requirements on routing, quality of service (QoS), and network reliability.

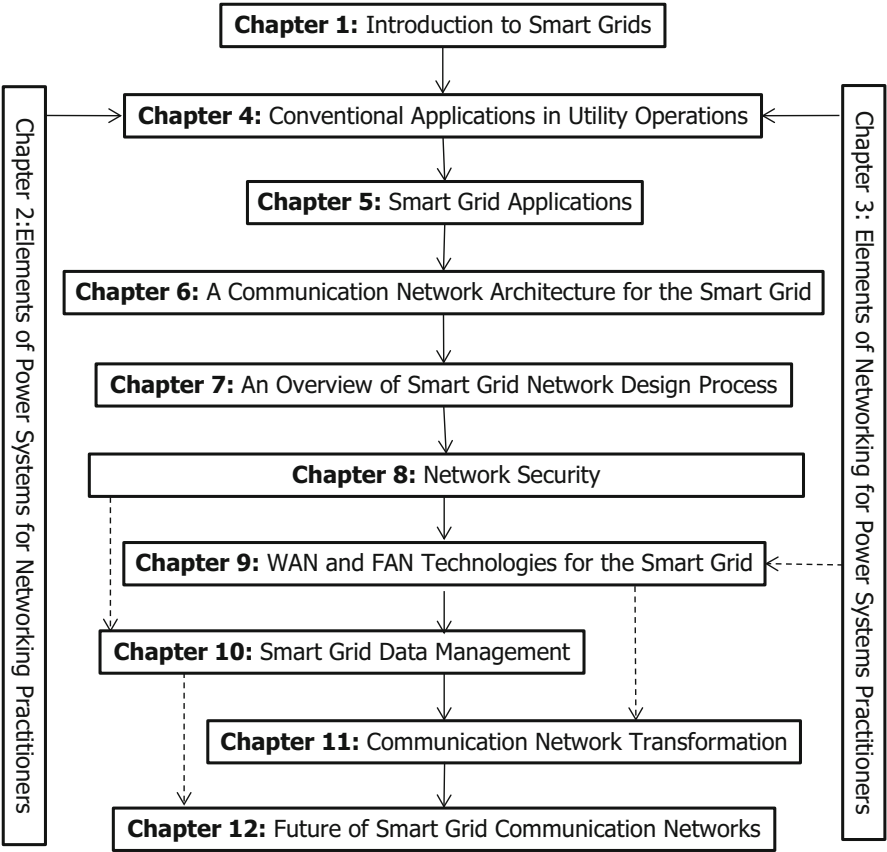
While security is briefly included in Chap. 7 in the context of network design, network security deserves a detailed treatment. Chapter 8 discusses network security for Smart Grid communication networks. Cybersecurity of the power grid has become as important as physical security. There has been a concerted effort by utilities, regulators, and standards bodies to implement a high level of communication network security that will not only secure the networks but also minimize the possibility of attacks on the grid and help mitigate and eliminate security threats. A security architecture with multiple security zones is presented.

Chapter 9 provides an overview of communication network technologies appropriate for WANs and the FANs. For WAN, optical networks are discussed in detail since many utilities already own or plan to deploy significant fiber infrastructure with optical ground wire (OPGW). Both wireline and wireless networking technologies are considered with special emphasis of their use as FANs. A more detailed treatment is provided for power line communication (PLC) technology since it is not a very commonly deployed technology in NSP or most enterprise networks. Similarly, long-term evolution (LTE) technology is described in detail in this chapter, since LTE has the promise of the most appropriate wireless broadband network technology for Smart Grid endpoints that need to be connected over wireless networks. Benefits and drawbacks of all technologies for their use in the FANs are summarized in a table. The chapter ends with a discussion on benefits and drawbacks of utility ownership of one or more of these network components in comparison to using carrier data networking services.

Smart Grid brings with it an enormous growth in data that must be managed for use by an ever-growing number of utility applications. Smart Grid data management is discussed in Chap. 10 in the context of data collection, storage, and access across the communication network. The traditional practice of client-server communication between individual applications and individual data source (such as smart meters, intelligent electronic devices, and synchrophasor) is not scalable. Further, this end-to-end communication has inherent security and data privacy risks. There have been recent advances in secure data management that are particularly suitable in the Smart Grid data management environment with network-based data storage and the corresponding middleware that affords highly secure and low-delay access to the data. In this chapter, a secure data-centric data management architecture is discussed. The chapter ends with a brief presentation of the elements of Smart Grid data analytics.

Chapter 11 brings together the concepts, technologies, and practices in the realization of communication networks for the Smart Grid. In this chapter, we present network transformation from the present mode of utility operation – of supporting all utility applications over multiple disparate networks – to an integrated network based on the Smart Grid architecture framework developed in this book. The network transformation process must weigh all available alternatives toward optimal network architecture and design that is sustainable for many years (typically between 5 and 20 years depending on a utility's planning horizon).

Planning for long-term network transformation described in this book is based on reasonable assumptions on future developments in new network technologies,



Interdependence of the book chapters

their availability to the utility in its service area, possibilities of using networking services from network service providers, and costs. While some of these futuristic elements and traits were considered in earlier chapters, a more focused discussion is presented in Chap. 12.

Interdependence of chapters of the book are shown in the figure at the top. Readers of each chapter will benefit from the material covered in the previous chapters. Power system professionals may skip Chap. 2 or skim through it. Similarly, communication networking professionals may skip Chap. 3 or skim through it. Readers with a significant background in Smart Grid and communication networking, or with an interest in the specific topics covered, may directly proceed to Chaps. 9, 10, or 11 after skimming through earlier chapters.

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