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Survey Paper

A survey on the communication architectures in smart grid

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ABSTRACT

The next-generation electric power systems (smart grid) are studied intensively as a promising solution for energy crisis. One important feature of the smart grid is the integration of high-speed, reliable and secure data communication networks to manage the complex power systems effectively and intelligently. We provide in this paper a comprehensive survey on the communication architectures in the power systems, including the communication network compositions, technologies, functions, requirements, and research challenges. As these communication networks are responsible for delivering power system related messages, we discuss specifically the network implementation considerations and challenges in the power system settings. This survey attempts to summarize the current state of research efforts in the communication networks of smart grid, which may help us identify the research problems in the continued studies.

1. Introduction

The current electric power systems have been serving us for more than five decades. They rely heavily on the fossil fuels, including oil, coal, and natural gas, as the energy sources. These fossil fuels are nonrenewable and the reserves on the earth are being consumed rapidly. The emerging energy crisis has called for global attention on finding alternative energy resources that can sustain long-term industry development. The identified renewable energy resources include wind, small hydro, solar, tidal, geothermal, and waste [1], which are also called *green energy* for the fact that they do not release carbon dioxide (CO_2) into the atmosphere in the process of electric energy generation. The renewable energy resources are important complements to and replacements of the fossil fuels for their exploitation durability and environment friendliness. In fact, active research studies and deployment activities are underway across the world [1,2] for effective harness of the renewable energy resources.

In the next-generation electric power systems that incorporate diversified renewable energy resources, automated and intelligent management is a critical component that determines the effectiveness and efficiency of these power systems. The management automation and intelligence are envisioned to offer a variety of advantages over the current systems in terms of digitalization, flexibility, intelligence, resilience, sustainability, and customization [3], which entitles the name *Smart Grid* to the next-generation power systems. The smart control centers are expected to monitor and interact the electric devices remotely in real time; the smart transmission infrastructures are expected to employ new technologies to enhance the power quality; and the smart substations are expected to coordinate their local devices self-consciously [3]. Enabled by the significant advancements in system automation and intelligence, the concept of *Energy Internet* [4] has been proposed that envisions an exciting prospect of the future energy utilization paradigm throughout all the energy generation, storage, transmission and distribution phases.

As one of the enabling technologies, a fast, reliable and secure communication network plays a vital role in the power system management. The network is required to connect the magnitude of electric devices in distributed

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locations and exchange their status information and control instructions. The system-wide intelligence is feasible only if the information exchange among the various functional units is expedient, reliable and trustable. The current communication capabilities of the existing power systems are limited to small-scale local regions that implement basic functionalities for system monitoring and control, such as power-line communications [5–8] and the Supervisory control and data acquisition (SCADA) systems [9–12], which do not yet meet the demanding communication requirements for the automated and intelligent management in the next-generation electric power systems. The future power systems comprise of a diversity of electric generators and power consumers that are located distributively over vast areas and connected all together into the same management network. Real-time bidirectional communications are the foundations to support the comprehensive power system management tasks which, in certain cases, require time-sensitive and data-intensive information exchange.

Apart from power systems, networking technologies have gained tremendous development in the past decades as a separate industry sector. The creation of the Internet, mobile cellular networks, satellite networks, community networks, wired and wireless local area and personal networks, as well as the invention of diversified networking services has enormously enhanced our capability for information exchange. However, the modern networking technologies have not been leveraged sufficiently in power systems for optimized management. When we develop the smart grid, it is critical to take advantage of the advancements in networking technologies to enable the automated and intelligent system management. Although the currently available networking technologies have greatly satisfied our personal communication needs, applying them to power systems and addressing the specific requirements for power communications are challenging by all means. We need to identify the communication scenarios and characteristics in power systems and develop practically usable network solutions. Particularly, our network infrastructures should be able to meet the promptness, reliability and security expectations of the power system communications.

At this transitional phase of shifting to the next-generation electric power systems, the study on the communication architectures for automated and intelligent system management is still at a primitive stage. Many technical challenges are awaiting solutions. To position our current research work and direct our future research effort, we are motivated to present this survey on the network infrastructures to be used in the next-generation electric power systems. As the research and development of these power systems are evolutionary, this survey may not include all the relevant information exhaustively, but it provides a preliminary summary of the current status and the future expectation of the smart grid research.

The rest of this survey is organized as follows. Section 2 describes the smart grid structures and expectations. Section 3 presents the communication architecture in the smart grid and the communication requirements. Sections 4 and 5 discuss the most challenging communication issues in the smart grid, namely, the delay, reliability and security. Section 6 describes the typical communication scenarios. The communication standards and experiments are discussed in Sections 7 and 8 respectively. Section 9 concludes this survey.

2. Smart grid framework and expectations

The communication architectures to be used in the smart grid provide the platform to build the automated and intelligent management functions in power systems. The functional requirements of communication architectures depend on the expected management tasks. To better understand our research goals on the communication networks that support the system management, we first discuss the vision and framework of smart grid. For ease of presentation, we list in Table 1 all the smart grid related acronyms used in this article.

2.1. Smart grid reference model

In the smart grid, many distributed renewable energy sources will be connected into the power transmission and distribution systems as integral components. The typical renewable energy sources include wind, solar, small hydro, tidal, geothermal, and waste. These sources generate extra electricity that supplements the electricity supply from large power plants and, when the electricity generated by distributed small energy sources exceeds the local needs, the surplus is sold back to the power grid.

Table 1
Acronyms in smart grid.

Acronym	Definition
AMI	Automatic metering infrastructure
AMR	Automatic meter reading
BAS	Building automation system
DER	Distributed energy resource
DLC	Direct load control
DMS	Distribution management system
DR	Demand response
EMS	Energy management system
ESI	Energy services interface
GPS	Global positioning system
IED	Intelligent electronic device
IEM	Intelligent energy management
IFM	Intelligent fault management
IHD	In-home display
ISO	Independent system operator
LMS	Load management system
MDMS	Metering data management system
OMS	Outage management system
PEV	Plug-in electric vehicle
PLC	Power line communication
PMU	Phasor measurement unit
PTP	Precision time protocol
RTO	Regional transmission operator
RTP	Real Time Pricing
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
STNP	Simple time network protocol
WACS	Wide area control system
WAMS	Wide area monitoring system
WAPS	Wide area protection system
WASA	Wide area situational awareness