Electrical Power and Energy Systems 63 (2014) 473–484

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A survey on Advanced Metering Infrastructure

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ARTICLE INFO

Article history:
Received 19 April 2014
Received in revised form 11 June 2014
Accepted 16 June 2014

Keywords:
Advanced Metering Infrastructure
Smart metering
Smart Grid

ABSTRACT

This survey paper is an excerpt of a more comprehensive study on Smart Grid (SG) and the role of Advanced Metering Infrastructure (AMI) in SG. The survey was carried out as part of a feasibility study for creation of a Net-Zero community in a city in Ontario, Canada. SG is not a single technology; rather it is a combination of different areas of engineering, communication and management. This paper introduces AMI technology and its current status, as the foundation of SG, which is responsible for collecting all the data and information from loads and consumers. AMI is also responsible for implementing control signals and commands to perform necessary control actions as well as Demand Side Management (DSM). In this paper we introduce SG and its features, establish the relation between SG and AMI, explain the three main subsystems of AMI and discuss related security issues.

1. Introduction

With emerging challenges and issues in the energy market of the 21st century, changes in the electrical systems are inevitable. The changes in the conventional ways of generation, transmission and distribution of power have brought along new challenges. The challenges to power industry include (but are not limited to): introduction of Distributed Energy Resources (DER), improvement of delivered power quality, environmental concerns over conventional and centralized methods of power generation, privacy of consumer's information and security of the system against external cyber or physical attacks, economics of power systems, from maintenance costs to equipment renovation and network expansion and last but not least, needs for better control schemes for complex system. The developed control schemes shall be able to address numerous uncertainties due to load distribution and integration of new sources of energy, as well as integration of electrical storage systems into the grid [1]. For many years utility providers have been concerned about the power quality and the economy of power system; however, security and privacy of information are the newly emerging challenges due to the incorporation of new technologies. Utilization of DER as renewable energy plays an important role in sustainability of the system. Although DERs are part of the solution, they are not easy to use since they add to the complexity of the control system. To address some of these challenges, Europe and North America modernized their energy generation and distribution systems and switched to Smart Grid (SG).

While the first electrical grids date back to the late 1800s, the 1960s were the golden era of power grids in developed countries. In this era, the distribution network's penetration rates and their load delivery capacity were high, reliability and quality of delivered power were satisfactory and centralized power generation in fossil, hydro and nuclear plants were technically and economically boomed. The last decades of the 20th century experienced an increase in electric demand due to the introduction of new consumers, such as entertainment industry, and dependency on electricity as the main source of heat and ventilation. The latter was due to the increasing price of fossil fuels. Furthermore, there was

Abbreviations: SG, Smart Grid; AMI, Advanced Metering Infrastructure; DSM, Demand Side Management; DER, Distributed Energy Resources; MDMS, Meter Data Management Systems; BPL, Broadband over Power Line; PLC, Power Line Carrier; AMR, Automatic Meter Reading; IHD, In-Home Displays; DER, Distributed Energy Resources; HAN, Home Area Networks; DR, Demand Response; GPRS, General Packet Radio Service; CIS, Consumer Information System; OMS, Outage Management System; ERP, Enterprise Resource Planning; MWM, Mobile Workforce Management; GIS, Geographic Information System; TLM, Transformer Load Management; LS, Load Signature; ELI, Electric Load Intelligence; PbD, Privacy by Design; NTL, Non-Technical Loss; T&D, Transmission and Distribution; COSEM, Companion Specification for Energy Metering; DLMS, Device Language Message Specification; CT, Current Transformer; LTE, Long Term Evolution; LTE-A, Long Term Evolution-Advanced; IDS, Intrusion Detection System; ACL, Access Control List; NSM, Network and System Management; PKI, Public Key Infrastructure; ISMS, Information Security Management System.

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http://dx.doi.org/10.1016/j.ijepes.2014.06.025
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significant fluctuation in the rate of energy consumption. With increased demand at peak times, more generation plants were required to avoid voltage drops and decline in power quality. However, the new plants were costly. On the other hand, the consumption rates were lower at night time causing an unbalanced consumption that left the plants' production capacity idle. Therefore, to promote a more even consumption pattern, the electricity industry tried to encourage its consumers to manage their consumption through offered incentives by changing its approach to Demand Side Management (DSM). The 21st century came along with innovations and advancements in different sectors that allow enhancement of Smart Grid concept. The improvements in Information Technology and communication industries along with introduction of smart sensors eliminated the restriction of precise consumption measurement for each consumer and allowed adaptive billing mechanisms to financially motivate consumers shift their consumption to off peak times. Improvement in renewable energies such as wind, solar, tidal or geothermal, combined by environmental concerns led to integration of these technologies into electrical systems to form decentralized generation. Electrical storage systems were also developed to address power management issues [2].

Smart Grids modernized the traditional concept and functionality of electrical grids by using Information Technology to obtain network components' data, from power producers to consumers, and use it properly to maximize the efficiency and reliability of the system. There is no clear or fully agreed boundary and definition for intelligence of a Smart Grid, as there are a number of factors involved in designing such a system. However, it is unanimous that for an efficient SG design interaction among three fields of communication, control and optimization is essential. The ideal Smart Grid design should address reliability, adaptability and prediction issues [1–3]. It should also address the challenges to load handling and demand adjustment, incorporation of advanced services, flexibility and sustainability, end to end control capability, market enabling, power and service quality, cost and asset optimization, security, performance, self-healing and restoration [1–3]. Since the introduction of SG, many studies in both industry and academia have been conducted in an attempt to put the concept into practice. Although the achievements are huge, there is still plenty of room for improvement. While SG has addressed some of the initial challenges, it has introduced new ones.

This survey introduces the AMI technology and its current status, as the foundation of SG, which is responsible for collecting all the data and information from loads and consumers. To the best of our knowledge, no previous published work has been dedicated to AMI, its building blocks and the critical issues relevant to the technology. The authors' motivation was to introduce AMI and present the related information in one consolidated, yet abridged work, in a simple and easy to understand language. The hope is that this paper provides basic information regarding AMI to future researchers, utility companies, technicians and manufactures.

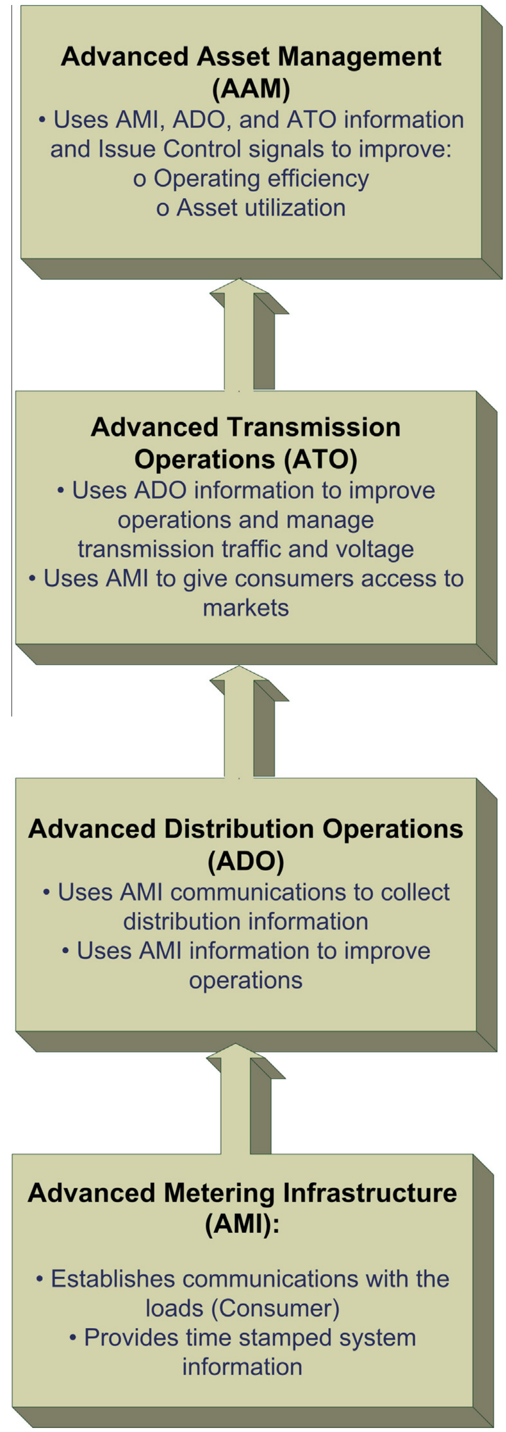

Fig. 1. An overview of Smart Grid sub-system sequence.

2. Advanced Metering Infrastructure (AMI)

2.1. Introduction

To achieve an intelligent grid, a succession of sub-systems should be realized. The solid establishment and functionality of each sub-system is instrumental in overall SG performance, as each layer's output serves as the feed for the next layer. Fig. 1 depicts this relationship and summarizes the role of each sub-system in development of the grid [4].

AMI is not a single technology; rather, it is a configured infrastructure that integrates a number of technologies to achieve its goals. The infrastructure includes smart meters, communication networks in different levels of the infrastructure hierarchy, Meter Data Management Systems (MDMS), and means to integrate the collected data into software application platforms and interfaces [4]. As shown in Fig. 2, the customer is equipped with an advanced solid state electronic meter that collects time-based data. These meters can transmit the collected data through commonly available fixed networks, such as Broadband over Power Line (BPL), Power Line Communications, Fixed Radio Frequency, as well as public networks such as landline, cellular and paging. The metered consumption data are received by the AMI host system.