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Smart Grid Technologies: Next Generation Power Systems

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Abstract: 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, 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. While current power systems are based on a solid information and communication infrastructure, the new smart grid needs a different and much more complex one, as its dimension is much larger. This paper will focus issues on smart grid technologies. The main objective of this paper is to provide current state of the art in smart grid communications.

Keywords*:* smart grid communication, power system, renewable energy.

I. INTRODUCTION

"Smart grid" generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries. They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses. They offer many benefits to utilities and consumers mostly seen in big improvements in energy efficiency on the electricity grid and in the energy users' homes and offices.

The "grid" amounts to the networks that carry electricity from the plants where it is generated to consumers. The grid includes wires, substations, transformers, switches and much more [6]. Much in the way that a "smart" phone these days means a phone with a computer in it, smart grid means "computerizing" the electric utility grid. It includes adding two-way digital communication technology to devices associated with the grid. Each device on the network can be given sensors to gather data (power meters, voltage sensors, fault detectors, etc.), plus two-way digital communication between the device in the field and the utility's network operations center [6].

A key feature of the smart grid is automation technology that lets the utility adjust and control each individual device or millions of devices from a central location. The smart grid is a modern electric power grid infrastructure for improved efficiency, reliability and safety, with smooth integration of renewable and alternative energy sources, through automated control and modern communications technologies [1] in the smart grid, reliable and real-time information becomes the key factor for reliable delivery of power from the generating units to the end-users. The impact of equipment failures, capacity constraints, and natural accidents and catastrophes, which cause power disturbances and outages, can be largely avoided by online power system condition monitoring, diagnostics and protection [4].

To this end, the intelligent monitoring and control enabled by modern information and communication technologies have become essential to realize the envisioned smart grid [1]

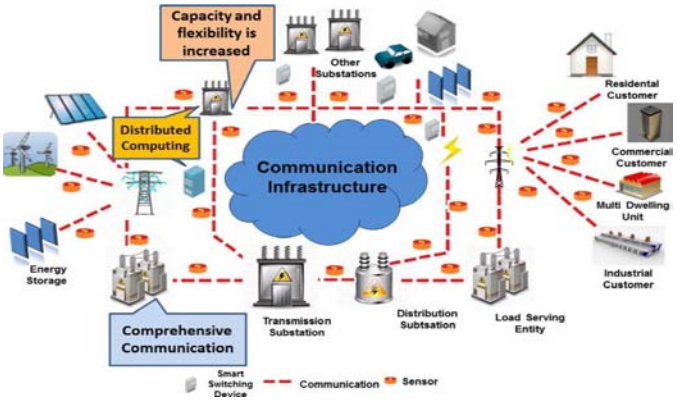

Figure. 1. Smart grid architecture increases the capacity and flexibility of the network and provides advanced sensing and control through modern communications technologies.

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II. COMMUNICATIONS TECHNOLOGIES AVAILABLE FOR SMART GRIDS

Different communications technologies supported by two main communications media, i.e., wired and wireless, can be used for data transmission between smart meters and electric utilities. In some instances, wireless communications have some advantages over wired technologies, such as low-cost infrastructure and ease of connection to difficult or unreachable areas. However, the nature of the transmission path may cause the signal to attenuate. On the other hand, wired solutions do not have interference problems and their functions are not dependent on batteries, as wireless solutions often do. Basically, two types of information infrastructure are needed for information flow in a smart grid system. The first flow is from sensor and electrical appliances to smart meters, the second is between smart meters and the utility's data centers. The first data flow can be accomplished through power line communication or wireless communications, such as ZigBee, 6LowPAN, Z-wave, and others. For the second information flow, cellular technologies or the Internet can be used. The available network technologies include the following categories:

a. Power Line Communication:

The power lines are mainly used for electrical power transmissions, but they can also be utilized for data transmissions. The power line communication systems operate by sending modulated carrier signals on the power transmission wires. Data rates on power lines vary from a few hundred of bits per second to millions of bits per second, in a reverse proportional relation to the power line distance. Hence, power line communication is mainly used for in-door environment to provide an alternative broadband networking infrastructure without installing dedicated network wires.

b. Wireline Network:

Dedicated wireline cables can be used to construct data communication networks that are separate from the electrical power lines. Depending on the transmission medium used, the wireline networks include SONET/SDH, Ethernet, DSL, and coaxial cable access network. SONET/SDH networks transmit high-speed data packets through optical fibers with supported data rate between 155 Mbps and 160 Gbps. Ethernet is popularly used in our homes and workplaces, providing a data rate between 10 Mbps and 10 Gbps. DSL and coaxial cable can be used for Internet access.

c. Wireless Network:

Advancement in wireless networking technology has enabled us to connect devices in a wireless way, eliminating the installation of wirelines.

In general, wireless signals are significantly subject to transmission attenuation and environmental interference. As the result, wireless networks usually provide Short distance connections with comparatively low data rates. Some wireless networks include The 802.11 networks, 802.15 networks & 802.16 networks. An overview of smart grid communication technologies can be found in Table I [2].

In the following, some of the smart grid communications technologies along with their advantages and disadvantages are briefly explained.

A. ZigBee:

ZigBee is a wireless communications technology that is relatively low in power usage, data rate, complexity, and cost of deployment. It is an ideal technology for smart lightning, energy monitoring, home automation, and automatic meter reading, etc.ZigBee and ZigBee Smart Energy Profile (SEP) have been realized as the most suitable communication standards for smart grid residential network domain by the U.S. National Institute for Standards and Technology (NIST) . The communication between smart meters, as well as among intelligent home appliances and in home displays, is very important. Many AMI vendors, such as Itron, Elster, and Landis Gyr, prefer smart meters, that the ZigBee protocol can be integrated into[5]. ZigBee integrated smart meters can communicate with the ZigBee integrated devices and control them. ZigBee SEP provides utilities.

- ***a. Advantages:*** ZigBee has 16 channels in the 2.4 GHz band, each with 5 MHz of bandwidth. 0 dBm (1 mW) is the maximum output power of the radios with a transmission range between 1 and 100 m with a 250 Kb/s data rate and OQPSK modulation. ZigBee is considered as a good option for metering and energy management and ideal for smart grid implementations along with its simplicity, mobility, robustness, low bandwidth requirements, low cost of deployment [5].
- ***b. Disadvantages:*** There are some constraints on ZigBee for practical implementations, such as low processing capabilities, small memory size, small delay requirements and being subject to interference with other appliances, which share the same transmission medium, license-free industrial, scientific and medical (ISM) frequency band ranging from IEEE 802.11 wireless local area networks (WLANs), WiFi, Bluetooth and Microwave

B. Wireless Mesh:

A mesh network is a flexible network consisting of a group of nodes, where new nodes can join the group and each node can act as an independent router. The self-healing characteristic of the network enables the communication signals to find another route via the active nodes, if any node should drop out of the network. Especially, in North America, RF mesh-based systems are very popular [5]. In PG&E's Smart Meter system, every smart device is equipped with a radio module and each of them routes the metering data through nearby meters. Each meter acts as a signal repeater until the collected data reaches the electric network access point. Then, collected data is transferred to the utility via a communication network [4].

- ***a. Advantages:*** Mesh networking is a cost effective solution with dynamic self-organization, self-healing, self-configuration, high scalability services, which provide many advantages, such as improving the network performance, balancing the load on the network, extending the network coverage range.

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b. Disadvantages: Network capacity, fading and interference can be counted as the major challenges of wireless mesh networking systems[4]. In urban areas, mesh networks have been faced with a coverage challenge since the meter density cannot provide complete coverage of the communications network.

C. Cellular Network Communication:

Existing cellular networks can be a good option for communicating between smart meters and the utility and between far nodes. The existing communications infrastructure avoids utilities from spending operational costs and additional time for building a dedicated communications infrastructure. Cellular network solutions also enable smart metering deployments spreading to a wide area environment. 2G, 2.5G, 3G, WiMAX, and LTE are the cellular communication technologies available to utilities for smart metering deployments[3].

a. Advantages: Cellular networks already exist. Therefore, utilities do not have to incur extra cost for building the communications infrastructure required for a smart grid. Widespread and cost-effective benefits make cellular communication one of the leading communications technologies in the market.

b. Disadvantages: Some power grid mission-critical applications need continuous availability of communications. However, the services of cellular networks are shared by customer market and this may result in network congestion or decrease in network performance in emergency situations[4]. Hence, these considerations can drive utilities to build their own private communications network.

D. Power line Communication:

Power line communication (PLC) is a technique that uses the existing power lines to transmit high-speed (2–3 Mb/s) data signals from one device to the other. PLC has been the first choice for communication with the electricity meter due to the direct connection with the meter [3] and successful implementations of AMI in urban areas where other solutions struggle to meet the needs of utilities. PLC systems based on the LV distribution network have been one of the research topics for smart grid applications in China

a. Advantages: PLC can be considered as a promising technology for smart grid applications due to the fact that the existing infrastructure decreases the installation cost of the communications infrastructure. The standardization efforts on PLC networks, the cost-effective, ubiquitous nature, and widely available infrastructure of PLC, can be the reasons for its strength and popularity. Data transmissions are broadcast in nature for PLC, hence, the security aspects are critical.

b. Disadvantages: There are some technical challenges due to the nature of the powerline networks. The power line transmission medium is a harsh and noisy environment that makes the channel difficult to be modeled.

Table 1: Smart Grid Communications Technologies

	Technology	Spectrum	Data Rate	Coverage Range	Application	Limitations
	GSM	900-1800MHz	Up to 14.4Kbps	1-10Km	AMI,Demand	Low Date rate
					Response	
	GPRS	900-1800MHz	Up to 170 Kbps	1-10Km	AMI, Demand	Low Date rate
					Response	
	3G	1.92-1.98GHz	384Kbps-2Mbps	1-10Km	AMI, Demand	Costly Spectrum
					Response	fees
	WiMax	2.5GHz-3.5GHz	Up to 75 Mbps	1-5Km	AMI, Demand	Not Widespread
					Response	
	PLC	1-30MHz	2-3Mbps	1-3Km	AMI,Fraud	Noisy Channels
					Detection	
	ZigBee	2.4GHz-868-	250Kbps	30-50m	AMI,HAN	Low Data rate
		915MHz				

III. APPLICATIONS OF SMART GRID

The number of applications that can be used on the smart grid once the data communications technology is deployed is growing as fast as inventive companies can create and produce them. Benefits include enhanced cyber-security, handling sources of electricity like wind and solar power and even integrating electric vehicles onto the grid [1, 2]. The companies making smart grid technology or offering such services include technology giants, established communication firms and even brand new technology firms.

The smart grid's biggest potential in delivering carbon savings lies in providing cost-effective and increasingly clean energy for electric vehicles, including plug-in electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs). Research work is being carried out in aspects like advanced metering infrastructure (AMI) that can enable the end users to purchase energy at off-peak hours and sell unused, stored energy back to the utility providers during peak hours at better tariffs. AMI is a means to facilitate two-way communication, interval metering, and time-based billing that enables dynamic pricing to be an option for all customers. With time-of-use pricing provided in a smart grid environment, a person could, for example, program a dishwasher to do its power-hungry job in the middle of the night in order to take advantage of lower

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tariffs. Advantages of network connectivity include automatic alerts being sent to the owners in case an appliance malfunctions, and remotely servicing configuration of machines by relevant customer service personnel [8].

IV. CONCLUSION

A smart grid is uses various wireless technologies to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

Our survey summarizes the currently working technologies & communication networks in the next generation power systems. Many research works is still necessary for intellectual power execution & to fulfill the different energy requirement.

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