

Survey of Smart Grid from Power and Communication Aspects

Abolfazl Azari

Young Researchers and Elite Club, South Tehran Branch, Islamic Azad University, Tehran, Iran

Abstract : A smart grid is a modern electric power grid infrastructure for enhancing efficiency and reliability using modern communication and control technologies. Smart grid can be considered as an outcome of a developmental electricity networks towards an optimized and sustainable energy system. The current power systems are based on solid communication whereas, smart grid technology is based on grid-integrated communications between various grid elements, transmission and distribution using sensing and metering technologies and modern energy management techniques. This paper describes various smart grid concepts and details.

Key words: Smart Grid • Power • Communication Technology

INTRODUCTION

The Traditional power grids use one way communication for power distribution from central generators to large number of users. In contrast, smart grid uses two way communications to create an automated and advanced power delivery network. Smart grid exploits many advanced technologies such as, geographical information systems and wireless communications.

The smart grid can be considered in four main components: advanced metering infrastructure, advanced distribution operations, advanced transmission operations and advanced asset management. These technology improvements, will allow widespread use of renewable energy to compensate carbon emissions. The advanced metering infrastructure allows two-way communications between utilities and customers and provides a variety of information, such as real-time pricing and usage information. This will enable customers to get feedback from real time electricity prices and allow to better management and control of their consumptions [1].

Advanced distribution operations Improves the distribution system with automated devices for increasing the efficiency and reliability of electricity. These technologies can decrease power outages, service disturbance and speed of restoration automatically [1].

Advanced transmission operations connects large regional operations which transfer electricity from power plants to local distribution centers. These technologies will reduce congestion on the lines and transmission line losses [1].

Advanced asset management provides information in real-time about operations of the electric grid. This will minimize the impact of outages on consumers and improve electric consumption forecasts. By applying advanced asset management with other smart grid improvements, the costs associated with operations and maintenance can be decreased [1].

This survey is arranged in five sections. In section II, we present smart grid in power system accomplished with power generation, transmission grid, distribution grid and metering and measurement. We then describe the smart grid communication technology including ZigBee, cellular network and WiMAX in section III. In section IV, we review the smart grid communication requirements. Finally, the conclusions are summarized in Section V.

Smart Grid in Power System: Power system significantly related to the operation that obviously involved with the electricity generation, electricity transmission, electricity distribution and electrically control process for the particular above parameters mentioned. For the decades, power grid has been interpreted as one way delivery system [2], consist of transmission grid and distribution

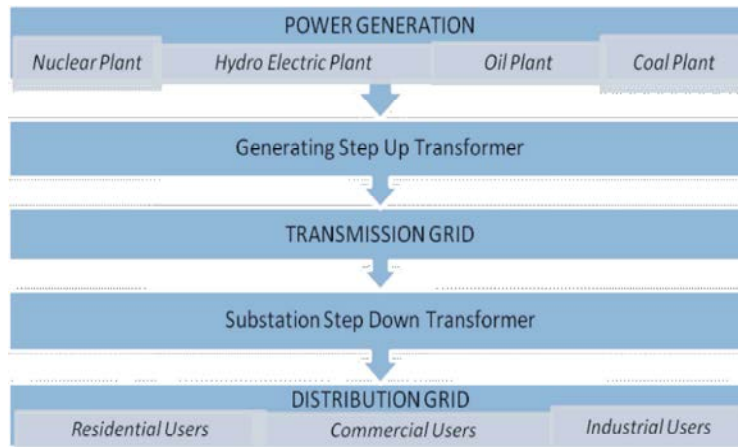


Fig. 1: An example flow of conventional power grid

grid illustrated sequentially as Figure 1, beginning from a power generated by a few types of power plants such as hydro electric plant, oil plant, nuclear plant and coal plant, where this electric power generated first will need to be step up to a higher voltage for transmission purpose. Along the transmission lines, the power flows through the long distance to the transformer at the substation for stepping down from transmission level to the distribution level before feed back to the service location area and then again the power is stepped down from the distribution level to the suitable voltage required and demanded by the end users.

Opposite of the conventional way above, the smart grid in power system has been introduced due to the modern technologies. The system is more reliable, flexible, efficient and sustainable due to the transformation from a one way into two way operation, utilizing the system with current information technologies that spread widely into the modern world, cyber-secure communication technologies and computational intelligence [3] in a way to execute the whole process of generation, transmission, substations, distributions and consumption of the electricity.

In existing one way operation power system mentioned earlier, for the example, power source are fully rely on the transformer connecting to the flow of the grid only, whereas, smart grid can break that domain power flow pattern (refer to Figure 1) like distribution grid to another power sources such as solar panel systems or wind turbines to generate an electricity [4]. With the information advantage, smart grid also can respond as fast as the data collected, on any events or malfunction probably happen to the system such as to change power flow and recover the power failure.

Table 1: U.S Electricity Generation by Source

SOURCE	%	
	2008	2009
COAL	48.70	44.90
NATURAL GAS	21.40	23.40
NUCLEAR	19.70	20.30
HYDRO ELECTRIC	6.10	6.90
OTHER RENEWABLES	3.00	3.60
PETROLEUM	1.10	1.00

Power Generation: The process of transforming source of energy such as natural gas, coal, nuclear power, sun and wind into electrical energy is known as electricity generation. Energy sources used to generate electric power in United States of America for two years respectively [5] are shown in Table 1. Thus, due to the decreasing of fossil fuel and increasing of the price, renewable energy is expected to take place in the future power generation. Therefore, smart power generation which is comprises the combination of two way flows of electricity and the information technologies, are developed to replace the existing conventional power generation grid. The distribution generation is the most important feature provided by the smart grid system. Small distribution generations from distribution energy resource systems such as solar panels, small wind turbine, micro turbines, photovoltaic, fuel cells and wind power turbines if use in a bulk, have a capability to operate equally or even better than the conventional large generators [6]. These will then drive to the improvement of delivering the power generation.

Instead of the benefit obtained, to implement of distribution generations as mentioned, a few weaknesses of the system should be thoroughly considered, such as

wide fluctuation due to the large scale deployments for generation from renewable source e.g. solar and wind and also high cost in distribution generators for generating one unit of electricity compared with the existing conventional way that uses large scale central power plants [6]. The future smart grid in conjunction with distributed generators has a possibility to form up the non-centralized power system distribution.

A large group of distributed generator needs a specific system to manage the high energy capacity compared to the conventional power plant. Linkage with this matter, a Virtual Power Plant comes across [7] as the method that developed by the technology of distribution generation. This virtual power plant uses central controller which is able to deliver peak load electricity at short notice and react better to fluctuations when more flexibility (more distributed generators) are allowed to integrate with the system. Although this will demand a complicated optimization and control as well as need a secure communication methodology to manage its complex system operation, this concept provides high efficiency and more flexibility rather than a conventional power plant.

Transmission Grid: Infrastructure of transmission side becomes more demanding tasks as increasing load requirement time to time and also the components used are usually not longer lasting, as well as the existence of innovative technologies such as new materials, advanced power electronics and communication technologies start to take part. These are among the significant factors that contribute in developing of smart transmission grids. The smart transmission grid is designed as an integrated system consists of three interactive components which are smart control centers, smart power transmission networks and smart substations [4]. The smart power transmission network basically is used in the elements on the existing electric transmission infrastructure and control centers. The further analysis can be done to monitor the system due to the emerging of new technologies such as new materials, electronics, communication, computing and signal processing. This new technologies will improve the power utilization, power quality, system security and reliability.

Over the years the basic configuration of high voltage substations are maintained without major changes even though the equipments have been changed concurrent with the new products and technologies [8]. This is what the vision of smart substation has been carried out, to built on the existing comprehensive

automation technologies of smart substations that capable to deal and give respond instantaneously, to make the grid become more flexible in control and operation, as well as the resilience and sustainability [4].

Distribution Grid: The aim of developing distribution grid collaborates with smart distribution grid is to deliver power to serve the end users in better way. Unfortunately, as many distributed generators will be integrated into the grid, this will increase the system flexibility for power and also give the implication to the power flow control. However this issue can be overcome by the investigation of smarter power distribution and the delivery mechanisms which are the most important and essential factors [4].

One of the solutions that has been proposed in distribution side is two in-home power distribution systems which is a circuit switching system based on alternating current (AC) power distribution and direct current (DC) power dispatching system via power packets which are added with the information technologies [9]. The combination of the information with the electric power will form a packet of energy but this packet's systems need some high power switching devices to drive them to operate. Power flow regulating will become easier by controlling these packets. DC based power distribution via dispatching system can change existing in-home power distribution to become more efficient and practical.

Metering and Measurement: The use of smart grid system can reduce the consumption of electricity and also the cost. The reduced cost from daily usage in household items can indicate effectiveness of the use of smart grid systems in the certain area.

As shown in Fig. 2, in electric distribution network, users will be connected via smart meter to their electrical appliances [10]. The users can be from home user, industrial user, building or commercial user. Each smart meter will control all sources of electricity including the flow of electricity and cost. Beside of using the wired technologies, the smart meter can also be connected wireless based on cellular technology [11].

With the use of smart meter in smart grid system, users can know exactly the use of electricity in their electrical appliances. The usage cost for each appliance can be calculated and users can check the electricity usage for each appliance according to user-defined.

Using computer-based management system, user can control the electricity that being supplied to their house [12]. One example of user specific setting that can be used

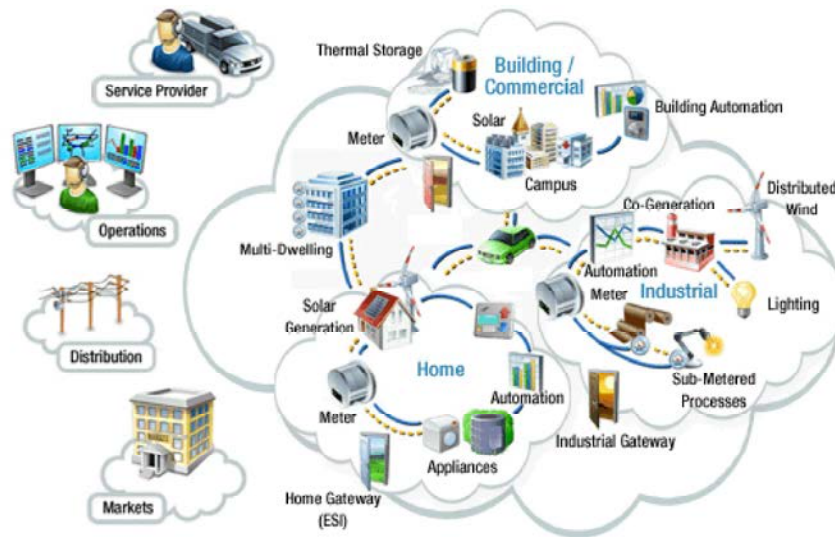


Fig. 2: Smart grid conceptual model for customer through smart meter

is deciding when to turn on/off the appliances during specific situations. If this method was applied into large scale area such as cities, town or even places where the use of electricity is crucial, the cost will be reduced greatly. The use of smart meters has been tested in Washington DC and shown the cost reduction. Consumers whose used this system, have been very satisfied and conceded that smart meters is useful and practical in modern life [13].

Smart Grid Communication Technology: In smart grid systems, a secure and cost-effective communication system is required to handle a huge amount of data from various applications. Communication technologies employed by smart grid can be classified in two main types of wired and wireless for data transmission. Low cost and easy deployment are the main advantages of wireless communication over wired communication, *i.e.* wireless communication is more popular in smart grid systems [14].

Customarily, two types of information in a smart grid system should be transferred. The first data is from sensors to smart meters and the second is from smart meters to data center. The first data connection can be performed via power line or wireless communications and popular systems for second information are cellular networks and internet [15]. In this section, we review some communication technologies which can be used for smart grid systems.

ZigBee: ZigBee is a free radio frequency network-based proprietary device, working in 2.4GHz, 868 and 928 MHz and based on the IEEE 802.15.4 standard which can be used in tracking real-time energy consumption.

The Advantages of Zigbee Are [16]:

- Low power.
- *Low Rate of 20~250kbps:* 250kbps (2.4GHz), 40kbps (915MHz) and 20kbps(868MHz).
- *Short Delay:* 15ms to wake up from sleeping mode and 30ms to access the network.
- *Self-organization:* Dynamic routing protocol is used to ensure reliable data transmission.
- *Large Scale:* 65,000 nodes can be supported at most.
- *High Security:* Three-tier security, including no security settings, using access control list (ACL) and advanced encryption standard (AES-128).

Figure 3 shows a home area network based on ZigBee technology. ZigBee can provide the ability of demand response and load control, mechanism for Time of Use pricing, messaging connection between customer and utility companies, real time usage information and remote monitoring in a smart grid system [16].

Cellular Network: The 2G, 2.5G, 3G and 4G cellular technology operates on 800/1900 MHz with data rate of 60-240Kbps can be a good option for data transmission in smart grid systems. The main advantage of cellular

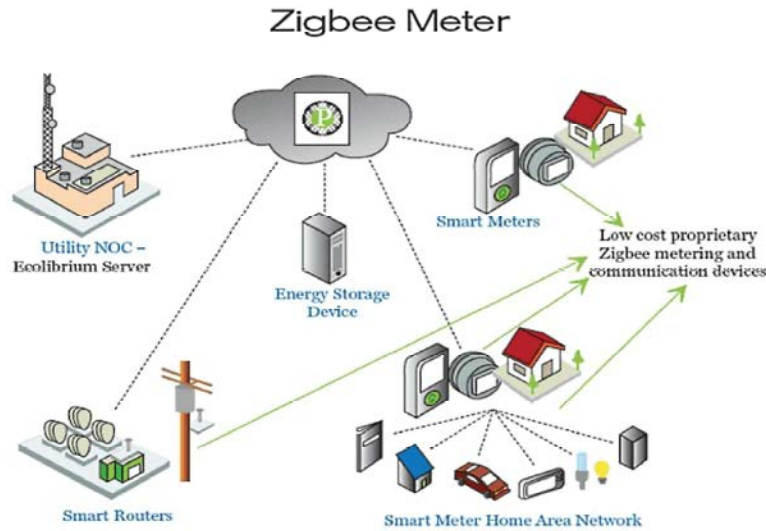


Fig. 3: Home area network on ZigBee technology.

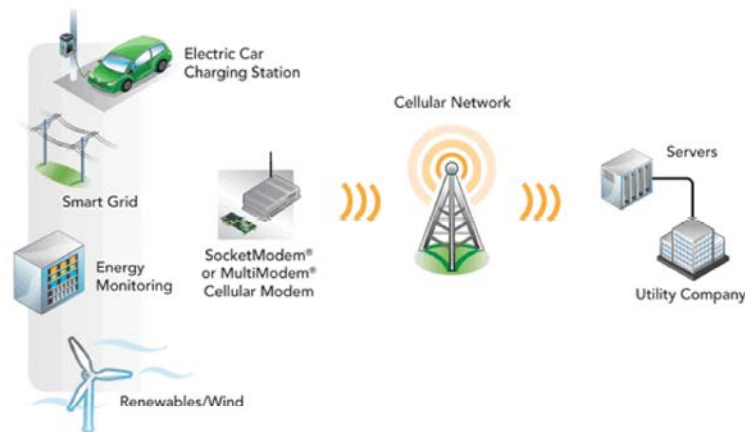


Fig. 4: Cellular network for smart grid systems.

technology is the existing communications infrastructure that can reduce the operational costs and time and enable easy deployments [17].

As shown in Fig. 4, the cellular technology can be used for monitoring the sensor information in real-time so electricity levels can be optimized to improve efficiency and reliability of power delivery.

Wimax: Worldwide inter-operability for Microwave Access (WiMAX) technology is a part of 802.16 series standards which uses 3.5 and 5.8 GHz bands for fixed communication and frequency bands 2.3, 2.5 and 3.5 GHz for mobile communication with data rate up to 70Mbps and distance up to 48km. WiMAX can be used for Wireless Automatic Meter Reading (WAMR), real-time pricing and outage detection and restoration in smart grid systems [17].

Figure 5 shows the WiMAX application in smart grid system. WiMAX can support a wide range of applications including, smart metering, asset management and surveillance and emergency communications.

Implementation of security protocols that protect sensitive data, traffic prioritization to allocate traffic among applications and sufficient bandwidth to deploy all required applications are the advantages of WiMAX technology [18].

Smart Grid Communication Requirements: Smart grid systems require secure two way communications with sufficient bandwidth between energy generation, transmission, distribution and consumption. In this section, we present the major smart grid communication requirements.

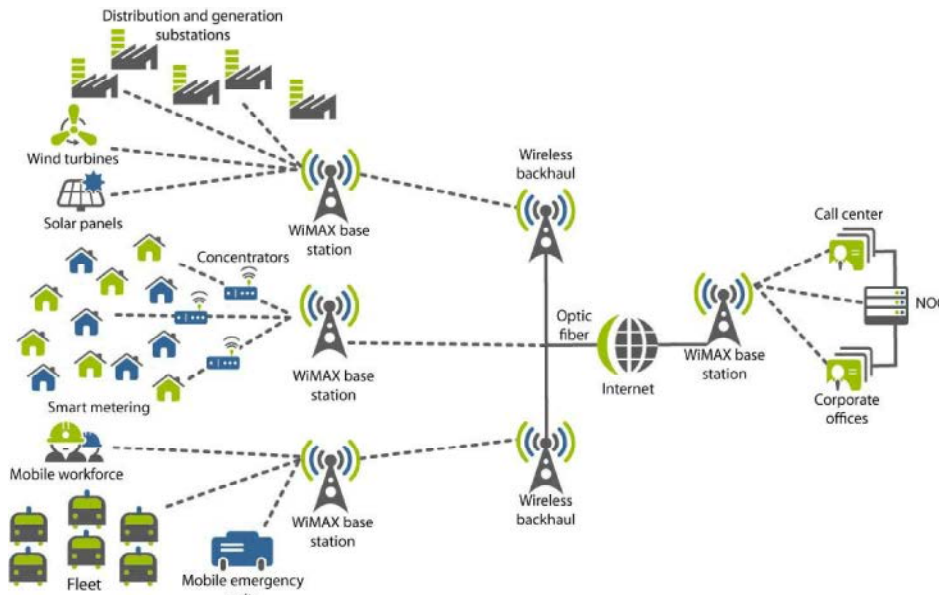


Fig. 5: WiMAX application in smart grid systems.

Security: Secure connection between suppliers and customers provides protection for applications and information as well as protections against security breaches [19]. Security must be planned at the elementary level, not added on later [20]. In addition, well-organized security system has a vital rule in grid control [21]. For an example of protection against unauthorized access which is a crucial requirement for usage and control data communicated within the system, the critical system functionalities require the data be trusted by both suppliers and customers [22]. To provide such a security services, several security tools and measures are used as elementary necessities in the smart grid system, like firewall, virtual private network (VPN), virtual local area network (VLAN), intrusion detection systems and intrusion prevention systems (IDS/IPS) and access control [19].

Reliability: Reliability clarifies the operational health and level of instability of the entire system [19]. In old power infrastructure, growing energy consumption and peak demand are some of the reasons that produce unreliability issues for the power grid [23]. Using the modern and safe communication and information technologies, faster and healthier control devices such as sensors for the entire grid from suppliers to customer resources will considerably strengthen the system reliability [23]. Reliability of the grid can be improved by deployment of sensors that prepare immediate situational awareness. Sensors now being widely used in the transmission grid, allow the system to detect and response failures and

anomalies in shortest period of time. Sensors in the grid could also detect when a transformer is spoiling and notice to replace it before a failure happens [24].

Quality of Service: The issue key of smart grid is communication between power supplier and power costumer. Failures in communication like delay or outage can compromise reliability of grid. Quality of service (QoS) mechanism is responsible to provide high-quality communication requirements and implement QoS protocol in communication network [25]. To achieve high QoS, two important questions should be answered [25].

- How to define the QoS requirement in smart grid?
- How to make sure the QoS requirement from the home appliance in the network?

To answer the first question, the mechanism of power price based on the amount of the load, should be probed. Then, a reward system can be constructed for the home appliance based on the power price and the utility task of the appliance. Thus, the influence of delay and outage on the reward of the home appliance can be obtained and the QoS requirement can be extracted by optimizing the reward [8]. To answer the second question, we focus on routing methodologies that meeting the derived QoS requirement. Because of the necessities of high computing and storage capabilities imposed by the heterogeneity of the smart grid, several QoS-aware routing within several constraints should be considered [26].

A QoS requirement typically contains some specifications, such as jitter, delay and probability of connection outage. To obtain the QoS requirement, it is essential to understand the dynamic probabilities of the power system to assess the influence of different QoS specifications on the smart grid system and to derive the QoS requirement from the similar effects [25].

To link several smart grid systems together properly, strong data communication infrastructure will be required. Power distribution line of the infrastructure can be used as a communication transporter such as PLC technology [27]. "One of the challenges of employing PLC in power distribution grids is multi hop transmission message routing. The basic idea is that network nodes, *i.e.*, PLC enabled devices, act as repeaters of messages in order to achieve sufficient coverage" [27]. The trouble of routing in PLC networks is that network nodes are static and therefore, their location is known in advance. This means, the nodes identify in which direction a message is planned to go. Particularly, if a node receives a packet, it can choose whether to forward it or not [28].

Routing protocol for low-power and lossy networks (RPL) was designed for compatibility in networks with low-power supplies lossy environments. RPL can be employed in both wired and wireless networks in difficult environments, for providing adaptive network operations [24]. A hybrid routing protocol that combines local agility with central control meets the requirements of strong collection, point to point communication [29]. It uses a distributed algorithm to make a Directed Acyclic Graph (DAG) for routing data from in-network nodes to boundary routers, allowing nodes to maintain multiple options that are ranked through data-driven link estimation [24].

CONCLUSION

Smart grid system is a computerized and consumer-oriented version of current power grid systems. It aims to achieve reliability, efficiency and operational optimization in power systems. Smart power infrastructure and advanced communication technologies are required to reach these targets.

In the first part of paper, an overview of smart energy subsystem has been presented. The possible communication technologies including ZigBee, cellular network and WiMAX for implementing in smart grid systems have been discussed with advantages and challenges. The recommended wireless technologies for smart grid systems can meet the communication requirements such as security, reliability and QoS.

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