Summary of Smart Grid

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Abstract. Energy sustainability and environmental preservation have become worldwide concerns with the many manifestations of climate change and the continually increasing demand for energy. As cities and nations become more technologically advanced, electricity consumption rises to levels that may no longer be manageable if left unattended. The Smart Grid offers an answer to the shift to more sustainable technologies such as distributed generation and micro-grids. A general public awareness and adequate attention from potential researchers and policy makers is crucial. This paper presents a summary of the Smart Grid with its general features, functionalities and characteristics. It presents the Smart Grid fundamental and related technologies and have identified the issues emerging. It introduces Smart Grid politics of US, EU, and China. It demonstrates how these technologies have shaped the modern electricity grid and continued to evolve and strengthen its role in the better alignment of energy demand and supply.

Introduction

A traditional power grid focuses on the generation, transmission, distribution and control of the electricity. In addition, the existing electrical grids have an electromechanical structure, one-way communication, centralized generation, fewer sensors, manual recovery, manual checks/test, some degree of control and fewer customer choices. However, a smart power grid is an intelligent electrical network used for improving efficiency, sustainability, flexibility, reliability and security of the electrical system by enabling the grid to be observable, controllable, automated and fully integrated. In contrast with the existing electrical grids, the intelligent electric grids have digital structure, two-way communication, distributed generation, numerous sensors, self-monitoring, self-healing capabilities, remote checks/tests, pervasive control and many customers. Moreover, a smart electricity grid opens the door to new applications with far-reaching impacts: providing the capacity to safely integrate more renewable energy sources, electric vehicles and distributed generators into the network; delivering power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities; using automatic grid reconfiguration to prevent or restore outages; enabling consumers to have greater control over their electricity consumption and to actively participate in the electricity market.

Smart Grid Functionalities

The Smart Grid proposes responses and solutions to the electricity supply adequacy concerns. The Smart Grid possesses following characteristics.

Reliability, Security and Efficiency of the Electric Grid

Reliable power supply is crucial to any power system. It determines the success of the grid in providing the needed service to the end users. Smart Grids improve fault detection and allow self-healing. As grids continue to grow in size and complexity, it becomes more difficult to analyze grid reliability but new analytical methods from research efforts have continued to build a stronger reliability foundation for modern networks. A data mining algorithm to discover grid system
structure from raw historical system data can estimate grid service reliability by using Bayesian networks. Remote monitoring of hybrid generation and automatic Smart Grid management for instable distribution main contribute to efficiency. The information network in Smart Grids allows for many features, and though prone to attacks, has been countered by promising solutions such as via an intrusion detection system (IDS) or by randomly hiding household sensitive information inside normal readings using wavelet based steganographic technique. Smart Grids systems threats analysis and integrated Systems Security Threat Model (SSTM) that help to better understand the weaknesses exploited by attackers, a game approach to address the issue of cyber-physical security of Wide-Area Monitoring and Protection and Control from a coordinated cyber-attack perspective can enhance security as well. Energy sector partnerships are managing cyber security while keeping critical energy delivery functions to ensure reliability in the modernized grid.

![Figure 1. A Smart Grid Perspective with all Components.](image)

Fig.1 illustrates a detailed sketch of a smart grid that consists of DG sources, conventional generators such as combined heat plants (CHP), fossil fuel based power plants, RES, and loads namely electric vehicle (EV), intelligent buildings, smart homes, and data center.

**Deployment and Integration Of Distributed Resources and Generation**

Distributed energy resources (DER) are small sources of power that can help meet regular power demand. DER such as storage and renewable technologies facilitate the transition to Smart Grids. The coming in of renewable energy sources as distributed generators can help mitigate the problems of depleting fossil reserves and the growing consumer demand. Distributed generation which include wind generators, photovoltaic generators, and battery storage systems may incorporate thermal generation and electric vehicles. The aggregation of these sources, however, also means that tremendous amounts of data would need to be handled and processed.

**Demand Response and Demand-side Resources**

Demand response is defined as “Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time”. Demand response provides consumers a chance to be involved in grid operations as they can reduce or shift their electricity usage during peak periods and benefit through financial incentives. Demand-side resources or energy efficiency and load management programs whose drivers include environmental, economic and reliability concerns have found growing investments.

**AMI and Distribution Automation**

Metering in Smart Grids enables two-way communication between the meters and the utility. The meters ensure more accurate bills and put consumers in control of their energy use. Smart meters, as they are normally called, involve sensors, power outage notification and power quality monitoring. Distribution automation is always associated with smart meters. With advanced metering infrastructure (AMI), utilities can collect consumer information faster and can provide a system-wide communications network to utility service points and link devices across the grid. The AMI and distribution automation opens the door for huge grid modernization though transformer
and feeder monitoring, outage management, integration of electric vehicles and effectual fault isolation. One way to achieve distribution automation is through the implementation of Substation Automation System (SAS) that defines locally control actions to solve congestion with minimal renewable energy sources curtailment.

Issues

Issues Emerging in Information and Communication Technologies

A smart grid information and communication infrastructure is needed for the data flow from sensors to smart meters and between smart meters and data centers. An integrated, flexible, inter-operable, reliable, scalable and secure two-way communication backbone needs optimized latency, frequency range, date rate and throughput specifications in order to meet the communication requirements of each smart grid component. Particularly, the information transfer and storage is ensured in a secure way for the purpose of avoiding the cyber-attacks. Many cryptographic protocols and algorithms, privacy-preserving billing protocols, encryption, decryption, authentication and key management schemes are proposed as the cyber-security solutions by the industry and academia to secure the smart-grid networks and devices. Smart grid communications are categorized as home area network, neighborhood area network and wide area network in terms of the covered geographic region, as depicted in Fig.2.

![Figure 2 The Architecture of Communication Layer in Smart Grids.](image)

Power line communication, wireless communication, cellular communication and internet based-virtual private networks are used in smart grid infrastructures. These technologies have their own challenges in terms of the usage in smart grids. Power line communication (PLC) is based on data transmission, sending the modulated carrier signals over the existing power line cables. It operates on the frequency ranges of 0.3–3 kHz for ultra-narrow band, 3–500 kHz for narrow band and 1.8–250 MHz for broadband. The time-varying channel conditions, the communication lost in open circuit ends of the power system, the reflections caused by impedance mismatches at discontinuities, strong low-pass behavior of the communication channel, signal attenuation and distortion, channel congestion, interference and noise issues are the main problems encountered with PLC. The data rates on power lines vary inversely proportional to the power line distance in PLC. In addition, PLC technologies necessitate the provision for real time communication, the enabling of high data rates, efficient coexistence mechanisms, durable security mechanisms and IP protocol support for the establishment in smart grids.

Issues Emerging in Sensing, Measurement, Control and Automation Technologies

A smart meter is an advanced energy meter that provides a real-time display of energy use, price information and dynamic tariffs with two-way communication and remote connect/disconnect capabilities. It may enable the automatic control of electrical appliances, power quality measurement, load management, demand side integration, outage notification and electricity theft-detection. All components and appliances in a smart meter network need specific ID numbers and therefore the integration of new devices becomes more complicated with an increasing number of customers. In addition, the integration of supplementary memory for storing the data logs
increases the deployment costs of smart meters. The utility companies benefit from mitigating the peak energy and selling the detailed billing data belonging to the customers.

Demand side management (DSM) allows customers to make informed decisions regarding their energy consumption, helps the energy providers to reduce the peak load demand and reshape the load profile. DSM is carried through demand task scheduling, usage of stored electric energy and real-time pricing. DSM techniques increase the operational complexity of the power system, redistribute the load but do not reduce the total energy consumed by the appliances. In case of loading the system with its maximum capacity, the value of DSM is high. Otherwise, it is low in systems with spare capacity. For this reason, the generation capacity of electricity grid represents the main challenges for DSM. On the one hand, the lack of knowledge about demand response (DR) programs, the response fatigue caused by keeping track of frequently varying prices and the extensive payback time for recovering the installation costs of smart meters are considered as consumer-based barriers. On the other hand, the existence of substantial confusion about whose responsibility the promotion of DR programs is, the loss of revenue for firm due to the lowering peak usage in case the electricity is more expensive and the lack of formal measures for the recovery of initial investment in DR infrastructure are regarded as producer-based barriers.

Current and voltage transformers, intelligent electronic devices, remote terminal units and bay controllers are the typical equipment of a substation automation system in smart grids. However, iron-cored current transformers create the measurement errors due to the presence of magnetizing current, flux leakage, magnetic saturation and eddy current heating. Leakage reactance, winding resistance, core permeability and core losses also affect the measurement accuracy of electromagnetic voltage transformers. An intelligent electronic device (IED) performs all the functions of protection, control, monitoring, metering, fault recording, and communication independently. Unfortunately, the overload data created by IEDs overwhelms the utilities, make the routine analysis of all data nearly impossible and brings out the necessity of automatic analysis tools for assisting engineers in decision support process. Especially, system operators realize slower and less confident actions which may possibly be incorrect for the current situation during the emergency situations where data collection is generally at its peak. In addition, the limited processing power of IEDs permits only the hard coded user names, requires the usage of simple and insecure service protocols, and constrains the implementation of host-based and distributed intrusion detection systems. Furthermore, IEDs have the limited flexibility owing to vendor-specific hardware and hardware-dependent software. The architecture of a modern substation automation system along with station, bay and process levels is illustrated in Fig.3.
Politics

Smart Grid policies worldwide show the increasing trend in providing a dependable framework to facilitate the development and deployment of Smart Grids.

United States

The US government energy policy aims for a secure supply of energy, keep energy costs low, and protect the environment by reducing consumption through increased energy efficiency, increasing domestic production of conventional energy sources, and developing new sources of energy, particularly renewable energy and renewable fuels. The US has invested in renewable energy resources and initiated modernization of its energy infrastructure. While the US is not a member of the Kyoto Protocol, it does have a carbon reduction target. The Global Smart Grid Federation Report of 2015 mentions that the US has a non-binding target of around 17% below 2008 levels by year 2020 under the Copenhagen Accord.

European Union

The EU aims to get 20% of its energy from renewable sources by 2020 and cut down greenhouse emissions, and rely less on imported energy. In 2010, the European Council adopted the 20:20:20 objective, reducing greenhouse gas emissions by 20%, increasing renewable energy to 20% and making 20% energy efficiency improvement by 2020.

Electricity Directive 2009/752/EC, requires EU members to implement smart metering in 80% of households by 2020. This however is subject to a positive cost-benefit analysis. The electricity sectors of the member states vary, so the roll out and their costs have to be individually dealt with. The European Commission also established the European Electricity Grid Initiative, a nine-year research and development program for Smart Grid technology and market innovations.

China

The basic contents of China's energy policies are "giving priority to conservation, relying on domestic resources, encouraging diverse development, protecting the environment, promoting scientific and technological innovation, deepening reform, expanding international cooperation, and improving the people's livelihood." The development of Smart Grids in China is incorporated in China's energy priorities. These include improving energy efficiency, increasing renewable energy mix and reducing carbon intensity. The Chinese government has tasked agencies like the National Development and Reform Commission (NDRC)—to oversee Smart Grid development plans, control electricity pricing and hold the authorization of review and approval of Smart Grid projects, the National Energy Agency (NEA)—to formulate and implement national energy policy and development plans, the State Electricity Regulatory Commission (SERC)—to supervise the daily operation of power generation companies and power utility companies, the China Electricity Council (CEC)—to assist in the formulation of power policies and lobby national Smart Grid plans, and the Ministry of Science and Technology (MOST)—to take charge of research and development, with Smart Grid technologies being one of the priorities in its 13th Five-Year Plan on National Scientific and Technological Development. China has given substantial attention to the development and emergence of Smart Grids.

Summary

The Smart Grid concept has evolved from a vision into a goal that is slowly being realized. As technology grew, devices and systems are able to support the formation of a more intelligent grid. Concrete energy policies facilitate Smart Grid initiatives across the nations. Smart Grid practices in different regions barely indicate competition but rather an unbordered community of similar aspirations and shared lessons.

The basic idea of the Smart Grid is not enough when embarking on this complex system. Even with experiences and technologies that are available for reference, the Smart Grid pursuit is an
investment of time, money and continuous investigation and testing. With large efforts put forth for
Smart Grid research, the Smart Grid can be more effective in helping attain energy sustainability
and environmental conservation and preservation. The exact future of the Smart Grid may be
difficult to predict, but recent innovations display a dynamic merging of sectors, mechanics and
communities.

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