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Research Article

Smart Grid Technologies in Power Systems: An Overview

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Abstract: The smart grid refers to next generation power grids, with multi-directional flows of electricity and information to make a wide distributed network. Through smart grid, the power system becomes smart by communicating, sensing, control and applying intelligence. For ideal system, the smart grid technologies are more compatible to permits many functions which can optimize with the combination of the use of bulk generation and transmission. The Smart grid is also kept the environment free from pollution; minimize the cost, effective operations, against all types of hazards and danger. In this review, we discuss the smart grid technology, its standard and recent challenges. We explore the different projects of the smart grid in developed countries and discuss the implementation challenges for undeveloped countries.

Keywords: Challenges, power systems, smart grid, standards, technologies

INTRODUCTION

Recently, the problem of voltage stability has deregulated the electric market and growth of energy consumption. Voltage system stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. The previous electromechanical grids have been based on vertical integrated utility structure to control and generate power. Recently, these power grids have the various different types of operational challenges such as reservations in the schedule, increasing penetration of renewable systems, etc. These challenges lead to unpredictable terrible events because of limited awareness of management staff and other physical and cyber-attacks. The consumers are always suffered from these voltage instabilities and demanding quality and better services of the power supply. Transforming electric grids into smart devices, electronics and computational algorithms into highly reliable and efficient smart grid is needed to overcome different challenges. Recently, the increasing demand for power transfers over long distance has emphasized the significance of stability in the power grid. Stability is referred to the ability of the grid to withstand disturbances and classified through the nature of disturbance of interest. To address these challenges, power industries, national laboratories and government have been established to overcome and handle the issues with designing future grids such as intelligent grid, smart grid, grid wise, etc.

Smart grid technologies have been used to distribute electricity and upgrade through two-way communications and pervasive computing capabilities for improve reliability, control, safety and efficiency. Smart grid delivers electricity between consumers and suppliers and control digital appliances to save energy and increase efficiency, reliability and transparency. It provides protecting, monitoring automatically for interconnected elements. It covers from generators via transmission network and distribution system for industries and home users with their thermostats and other intelligent appliances (Rahimi and Ipakchi, 2010).

In this study, we review smart grid technologies in power sector with different aspects. Further, the discussion is about smart grid standards and recent implementation challenges are discussed.

Smart grids: Recent advancement in communication and information technologies turned the way of operations in various fields such as banking, healthcare (Qureshi *et al*., 2014), industries (Qureshi and Abdullah, 2014), transportation (Qureshi and Abdullah, 2013) and power grids (Foster *et al*., 2008), etc. Basically, the smart grid concept is to provide grid observability, create controllability of assets, enhance security and performance with cost-effective operations, maintenance and system planning. Through smart grid technology, the new grid is expected to provide self-corrective, reconfiguration and restoration capabilities. The term of smart grid was introduced in 2005 (Amin and Wollenberg, 2005). According to DOE (department of energy) the modern grids initiative is sensing technologies, control methods and integrated communication into current electricity grid on distribution and transmission level. Table 1 shows the

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Table 1: Smart grid objective identified by DOE, USA

S/No.	Smart grid objectives
1	To accommodating all storage and power generation option
2	Scalable, enabling all new services, products and market
3	Cost effective and efficient in operating and assets utilization
4	Fulfill the 21st century needs in terms of power quality
5	Able to address disturbance by automated prevention, restoration and containment
6	Have operating capability to handle all types of hazards

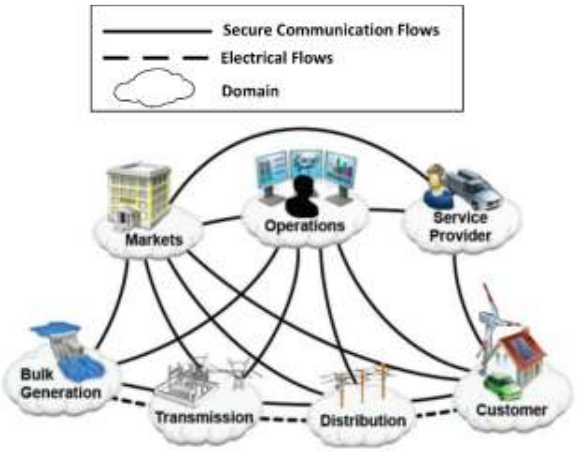

Fig. 1: Conceptual model of smart grid

main objectives of smart grid identified by the department of energy.

Developed countries are adopting effective and advanced power system techniques including North America, China, Europe, etc. Some countries already took benefits from smart cities such as earliest and largest project of the smart grid is 'Telegestore'. This project was implemented in Italy in 2005, where the company designed their own meters, system software, etc. This project is widely regarded and role model for commercial scale of adopting new smart grid technologies with effective cost and income (Mavridou and Papa, 2012). The city of Austin, USA, Texas has been working on the smart grid since 2003. Smart grid technologies are effective and beneficial for modern power systems in terms of technical solutions, economical point of view. Through smart grids, the power generation system is centralized and distributes. This technology recovers fault automatically and reduce transmission lines. The nature of smart grids is atomized and process real-time information from meters and sensors for fault location and automatically configures the feeders and voltage power optimization. Smart grid reduces the reactive power flow and enhances the real power to reduce the transmission losses. It can assimilate the renewable energy and distributed sources. The system is real time and two ways with theft detection capabilities. Various different technologies have been adopted by smart grid such as sensor networks, wireless mesh networks and intelligent and other interconnected technologies. According to National Institute of Standards and Technology (NIST) present a conceptual model of smart grid system and devices used as a reference for many parts of electric systems (Locke and Gallagher, 2010). This conceptual model categorized into seven domains. Each domain includes with different smart grid actors. Figure 1 shows the smart grid conceptual model presented by NIST.

Table 2: Comparison of existing grid and smart grid

Existing grid	Smart grid
Electromechanical	Digital
Centralized communication	Distributed communication
On-way communication	Two-way communication
Limited sensors	No limit
Manual restoration	Self-healing

The smart grid infrastructure divided into smart energy subsystem, information subsystem and communication subsystem. The traditional power grid is unidirectional and electricity generated with limited central power plants.

The generated electric power further pass to transmission grid and moves further. On the other hand compare to traditional power grid the flow pattern of energy generation in smart grid are more flexible due to distribution grid capability through solar plants and wind turbines.

Smart grid technologies: In general smart grid communication technologies are divided into 5 key areas: sensing and measurement, advanced components, decision support and improved interfaces, standards and groups and interacted communications (Yu *et al*., 2011). Smart grid distributes the electricity between traditional and distributed generation resources to the residential, industrial and commercial consumers. Through communication infrastructure, the smart monitoring and metering approaches provide real-time energy consumption. Via communication infrastructure the smart grid intelligent devices, dedicated software and control centers interact with each other. The role of communication infrastructure is crucial for effective smart grid operations (Vaccaro and Villacci, 2005). Existing electrical utility-wide area networks are based on hybrid communication technologies such as wired and fiber optics, power line communication, copper wire line and other wireless technologies. For data communication, a variety of communications technologies are used such as GSM, WiMAX and WLAN, etc., (Ghassemi *et al*., 2010). These technologies are designed to support smart grid applications in term of controlling and monitoring operations as SCADA (Supervisory Control and Data Acquisition), EMS (Energy Management Systems, DMS (Distribution Management Systems), ERP (Enterprise Resource Planning) systems, distribution feeder automation, generation plant automation, physical security, etc. Table 2 shows the comparison of existing grid and smart grid.

LITERATURE REVIEW

The traditional power systems are based on passive distribution with one way communication. The flow between consumers and suppliers is being changed into active distribution and the role of the consumer is automatically changing. The future electricity systems are smart grids with a bi-directional flow of communication between consumer and suppliers. Variety of literature has been proposed to improve the quality of these subsystems.

In this context, smart grid projects are the first step toward the future electricity systems. The smart grid project in Boulder, Colorado completed in 2008, where system used smart meters as a gateway for the home automation network to controlling the smart sockets and devices (Loeff, 2008-03). In Ontario, Canada Hydro one deployed smart grid with standard compliant communication infrastructure from Trillionth. In 2010, 1.3 million customers beneficial from this system. This system was the winner of Utility Planning Network award (Loeff, 2007). In Germany the smart grid project Broadband Power Line was implemented in model city Mannhein called MoMa project. Through smart city technologies, the many developed countries have been developed and solved their pollution issues such as carbon and massive greenhouse gas emissions. These countries have developed bi-directional power, home monitoring applications, etc. There are many different surveys have been conducted to elaborate the smart grid systems, (Hassan and Radman, 2010) briefly survey the basic concept of smart grid and its technologies, benefits and challenges. The further author illustrated the management role to establish the broad vision of smart grid. Samuelsson *et al*. (2006) reviewed the smart grid standards and recommendation for future smart grid standards. Vasconcelos (2008) highlighted the potential benefits of smart meters and give a concise review of the legal framework for governing policies and metering activities in Europe. Brown and Suryanarayanan (2009) reviewed in terms of industry perspective for the smart grid distribution system and highlighted these technologies for future research in the smart distribution system. Yan *et al*. (2012) discussed the smart grid in the security perspective. Chen (2010) discussed the privacy and security issues in smart grid and relates issues with cyber security on the internet. Some other authors discussed the communication networks for electric systems and provide efficient understanding for hybrid network architecture and heterogeneous systems and its application requirements (Gungor and Lambert, 2006). Akyol *et al*. (2010) reviewed the types of communication which are suitable for smart grid systems. Wang *et al*. (2011) discussed the communication architecture for electric systems such as technologies, requirements, functions and research challenges, etc. The Author also discussed the network implementation in power system settings.

There are many studied have been proposed and classified the smart energy into different energy subsystems: power generation, transmission grid and distributed grid. Power generation refers to generating electricity from natural gas, coal, nuclear, wind, sun, etc. A variety of studies have been proposed in these subsystems. A short review about the previous work in the field of power generation, transmission and distributed grid sectors in smart grid present in below section.

Andersen *et al*. (2008) proposed a software framework for generic virtual power plant called Service Oriented Architecture (SOA). Author tried to overcome the challenges in the field of power generation through proposed framework. In another study author (Caldon *et al*., 2004) proposed a framework for harmonizing the operations of different subjects. This approach is based on function models of system components. Jansen *et al*. (2010) proposed architecture for virtual plant, where trip-prediction algorithm proposed uses centralized approach to optimize for power balance, grid constraints, etc. Another effort (Lombardi *et al*., 2009) proposed to increase the amount of generators based on RES (Renewable Energy Sources) in power system. The author discussed the architecture and complex virtual power plant and its challenges.

Recently, the smart grid community focuses on technological and economic issues and incentives (Verbong *et al*., 2013). According to smart grid database in 2012, around 281 smart grid projects representing €1.8 billion investment in Norway, Croatia and Switzerland.

Smart grid standards: In 2001, the U.S Department of Energy (DOE) started a series of communication and controls workshops motivated on the integration of distribute energy resources. The Government of U.S also established the policy for smart grid, the first act came in 2007 with the name of energy independence and security act, In this act the advisory committee and intergovernmental agency task force; development and demonstration; frames technology research creates a funding program for smart grid investment (Lightner and Widergren, 2010). The second act is about recovery act 2009; this includes $3.4 and $615 million for smart grid and grand program. Many standards have been implemented in different areas, countries and organizations. Table 3 shows the list of main smart grid standards.

In order to promote the smart grid development, industries, governments, academia and industries have put an excessive deal of effort in pilot projects and programs.

Table 3: Smart grid standards

Country/organization	Standard
USA	NIST IOP (Locke and Gallagher, 2010)
Europe	CEN/CENELEC M/441 (CENELEC, 2009)
Germany	BMWi E-energy program, BDI initiative-internet der energie (Uslar *et al*., 2009; Rohjans *et al*., 2010)
China	SGCC (The State Grid Corporation of China, 2010)
Japan	METI (Japan, 2010)
Korea	Smart grid 2030 (Rohjans *et al*., 2010)
IEEE	P2030 (Microsoft, 2009)
Microsoft	SERA

IMPLEMENTATION CHALLENGES

There are various challenges exist during the implementation of smart grid projects. The one of the main challenge in less developed countries is unawareness and understanding of smart grid technologies at engineers and government levels. They need trainings through professionals or different companies, who have experience of smart grid technologies. The second challenge is finance matters because these types of projects need a large amount. For developed countries, this is not an issue because their economy is strong and they invest a lot in these types of projects such as USA, Germany, Canada, etc. On the other hand the less developed countries including Sri Lanka, Pakistan, Bangladesh, Iraq, etc., not bear the entire project cost because of limited resources and funds. The best option is to make a joint ventures with foreign investors start pilot projects and if the project is successful then the government will check further resources to invest for project expansion. Another challenge is policies regulations. Many developed countries already build smart cities with smart grids but still they are not clear to set the policies, regulations, guidelines and standards. The implementation of smart grids is another challenge because of its complicated design, planning and maintenance and operations. Only well organize with professional staff government organization can perform these tasks effectively. To educate the customers about smart grid operations and other services is another challenge. Print and electronic media are the sources to educate customers and highlight the benefits of smart grid technologies. The government of any country takes initiative for trainings and programs where customers will be taught about smart grids, its benefits and potential (Woodruff, 2004).

Security is a major challenge because the smart grid systems are controlled through the digital communications network, where important and private data are disseminated and store. So, there is a need for the proper mechanism to ensure security and privacy in systems. The security and cyber securities are major challenges of recent smart grids systems.

Table 4: Summary and literature of challenges in smart grid

Challenge	Description
Complexity (Cristaldi *et al*., 2002; Choi and Chan, 2004, Dougal *et al*., 2006; Dougal and Monti, 2007; Ponci *et al*., 2009)	Smart grid communication system is complex due to infrastructure of systems of systems.
Efficiency (Amin, 2005; Dollen, 2008; Krebs *et al*., 2008; Wen *et al*., 2010)	Smart grid has many challenges by harnessing modern communication and IT for grid wide coordinated monitoring capabilities.
Reliability (Mets *et al*., 2010; Moslehi and Kumar, 2010a, 2010b)	Need a framework for cohesive integration with reliability technologies with standards, protocols and analytical capabilities.
Security (Ericsson *et al*., 2007; Ericsson, 2010)	There are many issues are exist related to cyber security for power system communication infrastructure in smart grid.

The different types of challenges have been addressed and highlighted in smart grid literature; Table 4 shows the challenges of smart grid with related studies for further consideration.

CONCLUSION

The smart grid technologies have been started since when the technology was first introduced. The developed countries already change their traditional power systems into smart grids bust still they have some major issues related to policies, standards and security. The less developed countries still lagging far behind by every economical and technical aspect. But these countries taking strong initiatives to develop their manpower and spending more funds on smart grid projects. Smart grid technology is a beneficial technology for power system stability, customer's satisfaction, load distribution and all types of grid operations. The emergence of smart grid technologies will give friendlier environment for future, better power supplies services. Through this short review, the new researchers in the field of smart grids take benefits to understanding about smart grid, its standards and recent challenges for further research.

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