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Communications, Applications, Technology and Beyond: A Surveyon Smart Grid

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Abstract: The integration of information and communication technology in smart grid (SG) has revolutionized the infrastructure and capability of the current electric power.SG is a two way digital communication technology which is comprised of different sensors and is self-healing. In this paper, our contribution is twofold. Firstly, we aim to provide a structured and comprehensive overview of the research in SG. We group existing approaches based upon the architectures, applications and security solutions over the period 2010-2015. Secondly, we critically evaluate the performance of different SG technologies. Our finding can be used by different stakeholders who can tune this technology according to the 2020.

Keywords: Smart Metering, Advanced Meter Infrastructure, Power Line Communication, Wide Area Network, Communication Technologies

1. INTRODUCTION

The term grid is used for electricity system that supports operations such as generation of electricity their transmission how they are distributed and their management (control). Smart grid (also known as intelligent grid, future grid, smart electrical/power grid, inter-grid, intra-grid) represent the next generation of electrical power system and aims to revolutionize the production, delivery and use of electricity worldwide. Smart grid (SG) will emerge to be foundation of the nation's economy for the foreseeable future *et al.*, 2013). Financial and environmental encouragements as well as advancement in equipment are changing the structure of the established view of industrial system.



Fig. 1. Network Architecture of SG

Distributed power sources (DPS), and energy management systems (EMS) are dependent on the area level. The SG delivers the flow of electricity among suppliers and clients using a two way digital communication technology to control appliances at customer building or home to reduce cost, save energy and increase reliability, efficiency and transparency (Yan *et al.,* 2013). By utilizing modern information technology, smart grid is able of power delivery in more well-organized ways and responds to wide ranging situations and to proceedings that take place anywhere in the grid such as generation of power handling their transmission, consumption as well as their distribution and also adopt the corresponding strategies. In contrast, traditional power generators can deliver the power from a few fundamental generators to many customers and clients (Yan *et al.,* 2013).The existing grid have one way communication and the technology used is electromechanical. The sensors used in existing grid are very few in number and they have generation capability which is centralized. They are liked by limited amount of clients and the system can be monitored and restored manually. We comprehensively summarize the following salient features of SG below (Fang, *et al.,* 2012):

- •Used digital technology
- •In SG communication is two sided
- •Generation is distributed
- •They have sensors all over
- •Monitoring is automatic and also have capability of self-healing
- •Adaptive and islanding
- •liked by large amount of customers
- •Pervasive computing

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According to US department of energy, smart grid is self-healing, consumer friendly, highly reliable and power quality is good, it opposes cyber-attacks and optimizes asset utilization etc. There are different technological benefits of SG such as highly sophisticated design of distribution level, distribution automation system, low cost communication system, advanced digital meters, electrical vehicle, energy distribution assets, broadband communication for delivery application, for advanced protection closed loop system is used, real time angle and stability of voltage also detection of collapse etc. SG integrate these separate issues to exploit the benefits (Hassan & Radman, 2010).SG can be designed by using many tools which differs in performance as well as complexity evaluation measures such as power quality and reliability, preparation and calculation, dynamic optimization, management of data, analytical ability etc. various research project are available in the area of SG: EPRI intelligent grid EPRI advanced distribution automation, modern grid initiative etc.(Hassan and Radman, 2010). SG has become one of important application of Internet of Things (IoT) which is 21st century phenomena in which consumer object connecting to the web start communicating with each other through sensor and actuator. IoT is comprised of three concepts, i.e., *a)* things oriented such as tags, sensors, actuators, radio frequency identification RFID etc.; *b)*Internet oriented is Ipv6, IP for smart objects, web of things; and *c)* semantic oriented that is to show the issues of tags, sensors for application development. IoT is in general the worldwide network of inter-connected objects uniquely addressable, based on standard communication protocol. Smart metering is one of the important applications of the IoT for environmental sustainability and energy issues in coming years. Smart energy meters calculate the consumption of energy of consumer and also provide detail information to the utility by two way communication. IP based wireless sensor network are considered as one of the promising wireless communication technology applied in smart meter infrastructure.

This paper aims to provide an easy and concise view of the SG technology. The focus is on critical review of some of the factors involved in SG such as communication, applications and security challenges in SG. The rest of the paper is organized as follow. Section 2 reviews the related work. The security issues are discussed in Section 3. The performance comparison of SG is given in Section 4. The paper concludes in Section 5

2. RELATED WORK

According to Anthony Miller, "Smart grid creation will be a process that takes longer time that involves deployment and integration of smart equipment" (Wang and Leung, 2011).

A. Challenges of smart Grid

The demand for SG is increasing, however, following are some of the issues, SG is currently facing.

a. Global warming problem: The existing electric power system is serving us since many years and are mostly dependent on remnant fuels which includes natural gas (ordinary gas) and coal oil as the sources of energy. The fossil fuels usage for energy consumption results in increased global warming (Gungor *et al. 2*013; Su **and** Chow, 2012)

b. Extensive outages of power: The increased human dependence on electricity has made it critical and the outage could affect human lives and business.

c. Various energy demands and also their security guarantees: The availability of crude oil as main energy generation substance crucial. It is estimated that oil assets and their production ratio will last for next 40 years and the reserves v/s production ratio of ordinary gas is said to be around 60 years or more. As the problem of the ratio increases, the demand for alternative energy resources such as renewable energy increases which is independent of export/import rules and regulations. The security of the alternative energy resources is of major concern (Cardenas, *et al.*,2014).

d. Securing Autonomic energy sources and its use within catastrophe: The main applications of *SG* is its capability to automatically protect energy sources in catastrophic conditions. The design of such SG which can be resilient in disaster conditions is a major challenge.

e. Failures of the Grid: The electricity failure in developed countries is as follows: in Japan and South Africa (20-30 min/day), in Germany (30-40 min/day), USA, Italy (30-50 min/day), France, UK and Spain (50-100 min/day) and Australia (250 min/day) as reported in (Fang *et al.,* 2012).

Smart grid communication

Smart grid act upon a two way digital communication technology between consumers and suppliers used for electricity distribution. The interconnected objects operations are automatically optimized, monitored and protected .The home area network (HAN), data centers, neighborhood area network (NAN), business area network(BAN)are all included in communication infrastructure of smart grid that uses a bi-directional flow of information for the distribution of electricity among users to control the intelligent appliances with a reliable system and also reduce cost by saving energy (Pipattanasomporn,

et al., 2009). (**Table 1)** summarized main issues of smart grid (Gungor *et al.,* 2013). The communication technology in smart grid can be categorized into five main areas such as advanced and new components ,the ability to measure and sensing ,interfaces are improved and can support decisions , high standards and groups and at last the communication is integrated (Yan *et al.,* 2013). In this section, we discuss power line communication, smart metering, distributed energy resources, monitoring and controlling.

1. Power line communication: In (Dzung, *et al.,* 2011), power feeder lines are used by power line communication (PLC) in media communication The ripple control system that is first generation provide one way communication ,second generation have data rate low in which meter reading with automatic system is used and in third generation data rate is higher and is based on orthogonal frequency division multiplexing (OFDM) are used in SG, advanced metering management and distribution automation. The power line communication technology become one of the possible technology on power transmission for information exchange between customers and utilities with smart grid development (Cardenas *et al.,* 2014). According to (Ericsson *et al.,* 2010), the communication requirements for power system are real time operation and require power system control, telephony and tele-protection, administrative operation for which no real time communication is needed for interaction like fault location, security system, asset management etc. and administrative communications i.e., facsimile and voice communication.

2. Smart metering: It is an advance meter that uses two way communication between users meter to update the user for current power consumption and to communicate with the utility company for the collection of information for billing (Backer, 2007). They also suggest different tools of advanced metering infrastructure for billing and metering, for asset management/operation/power quality. The advanced meter infrastructure (AMI) is referred as data collection system as well as full measurement system which also include smart meters(customers meters), data management system and communication networks (Crossley, 2007).

3. Distributed energy resources (DER): The concept of generation of power and their transmission is now converted to integration of energy resources that are small such as the installation of solar and wind to a massively distributed energy resources. As discussed by the author of paper (Fangxing *et al.,* 2010) distributed energy resources contain Electronic power processor (EPP) that direct exchange of power with SG (smart grid) and switching power interface (SPI) that manipulate current received from smart grid. Paper *et al.,* 2010) described micro-grids without centralized supervisor the authors also show how the cooperative performance of EPPs have the potential to make full use of all energy storage units and renewable power sources while improving the transmission efficiency and power quality.

4. Monitoring and controlling: A grid known as distributed monitoring and control system is proposed to manage the power. The interest of exploring security power processor (EPP) that direct exchange of power with SG (smart grid) and switching power interface (SPI) that manipulate current received from smart grid. Paper (Tanti, *et al.*,2010) described micro-grids without centralized supervisor the authors also show how the cooperative performance of EPPs have the potential to make full use of all energy storage units and renewable power sources while improving the transmission efficiency and power quality.

5. Monitoring and controlling: A grid known as distributed monitoring and control system is proposed to manage the power. The interest of exploring security vulnerabilities pose to these systems over internet technologies or through communication network a rose at the evolution of supervisory control and data acquisition (SCADA) systems (Ten, *et al.,*2008).

B. SMART GRIDS LAYERS:

The four main layers of smart grid, function and application according to (Santacana, *et al.,* 2010)are the *Decision intelligence layer*: the smartness of SG lies in this layer it acts as human brain and consists of intelligent electronic devices, computer programs, and control centers. This layer controls scheduling, micro grid, detection of intrusion and counter measures, detection of voltage fail, weakness and monitoring of the oscillation of power. The second layer is *Communication layer*: Act like nerves, Propagate data from connected device to the controller grid and then back to the device. Its applications are in Wide area protection, monitoring and control, reliable and secure transmission of information. Third layer is *Actuator layer*: It acts as body's sensory and motor nerves and is responsible for muscles control and its functions include Self-healing, protection (self-setting), and online identification of problems. *Consumption layer*: Acts as muscles of the body which functions for efficiency of energy and demand reduction control.

a. **Motivation For Smart Grid**: The main reasons for following the infrastructure of communication in smart grid which is based on the operation of system, operation on the system, reliability and environmental aspects.

b. **Applications** The key applications of SG are: Advanced meter infrastructure, home energy management, overhead nerves and is responsible for muscles control and its functions include Self-healing, protection (self-setting), and online identification of problems. *Consumption layer*: Acts as muscles of the body which functions for efficiency of energy and demand reduction control.

c. **Motivation For Smart Grid**: The main reasons for following the infrastructure of communication in smart grid which is based on the operation of system, operation on the system, reliability and environmental aspects.

d. **Applications** The key applications of SG are: Advanced meter infrastructure, home energy management, overhead transmission line monitoring, substation automation, outage management, demand response management, meter data management, distributed energy resources and storage, electrical vehicles charging, vehicle to grid.

3. SMART GRID SECURITY AND PRIVACY

Smart grid security especially cyber security discussed in paper (Ericsson *et al.*,2010). In SG used of wireless sensors network provide the capability of monitoring, transferring, prediction and management for effective usage of energy but on the other side it also introduce some security challenges related to connectivity, privacy and security management as in (Yide 2012). **(Table 2)** describe different researcher's contribution to the security and privacy issues of smart metering, monitoring and measurement features of smart grid. The data is collected from paper (Fang *et al.*, 2012). The communication network (Smart, *et al.*,2010) exist in smart grid is also expected to have privacy and security issues like wireless mesh network that is considered reliable but also vulnerable to intelligent adversaries attacks.

4. PERFORMANCE

The performance comparisons of existing technologies for smart grid infrastructure are given in **(Table 3).**

Table 1 main issues related to SG(Gungor et al., 2013)

Main Issues	Summarized
Energy Infrastructure	Represent physical infrastructure for distribution of energy, generation of energy and their transmission. Sub-stations, Switches, Cap banksWires, Sensors Customers, Transformers, Meters, Storage
Communication Infrastructure	Exchange of information through Fiber, WiMAX, Radio frequency, ZigBee: operate in mesh network technology Cellular technology is best for wireless area network, HAN
Information Technology	Provides: Data storage, Computational intelligence, Transaction, Analysis, Modelingcommercial transactions, web visualization
Potential Application	Consumer side Advanced meter infrastructure (Zaballos, Vallejo, & Selga, 2011), Demand response, Data control, Home energy management, transmission and distribution side, Outage detection, Fraud detection, Distributed management, Supplier side, Distributed storage, Renewable generation, Distributed generation

Table 2 Contributions of Various authors towards Smart Grid Technology

	Applications	Attacks	Researchers	Contribution
Security	Smart metering		(Cleveland, 2008)	Studied security requirements(integrity, confidentiality, accountability, availability)
			(Fang et al., 2012)	Give example on idle attack
			(Lv, Mu, & Li, 2014)	Accomplish a key-wrapping adapter and fit it in an encryption system combine with mismatched key-management architecture in smart meters for maintaining many options of cryptosystems.
			(Berthier, Sanders, & Khurana, 2010)	Examine useful needs for intrusion detection and monitoring in AMI through a comprehensive examination of the different threats.
			(Varodayan & Gao, 2010)	Propose a method (Slepian-Wolf codes) that information theoretic confidentiality is guaranteed
			(Rome & Bloomfield, 2010)	Propose penetration test and show that current AMI system are vulnerable to theft as it is demonstrated
	Monitoring and measurement	False data injection attack, Load redistribution attack	(Yao Liu, Ning, & Reiter, 2011)	False data injection attacks is analyzed in electric power grids for state estimation.
			(Xie, Mo, & Sinopoli, 2010)	In deregulated electricity markets a cyber-attack known as false data injection attack is presented against the state estimation.
			(Sandberg, Teixeira, & Johansson, 2010)	A survey of stealthy false-data attacks against state estimators as is shown to corrupt applications data by hateful attackers.
			(Yuan, Li, & Ren, 2011)	Differentiate delayed attacking and immediate attacking goal. Load distribution attack concept.
			(Dan & Sandberg, 2010)	For system security two algorithms are propsed to maximize the devices utility.
Privacy	Smart metering	Disclosing fine-grained consumption of data to utility providers	(Fengjun Li, Luo, & Liu, 2010)	Proposed "distributed incremental data aggregation approach" that is in all smart meters from source meter to collector unit data aggregation is performed in routing of data. Homomorphic encryption is used for privacy.
			(Rial & Danezis, 2011)	For computing fine-grained meter readings they proposed a privacy protecting protocol
			(Efthymiou & Kalogridis, 2010)	Third party escrow method is proposed to authenticate the unknown meter redings..
			(Cuellar, Lopez, Barthe, & Pretschner, 2011)	Secure communication protocols for electricity meters and for detection of fraud in privacy maintaining manner are discussed.
			(Kalogridis, Efthymiou, Denic, Lewis, et.al,, 2010)	Show that home load signature can be moderated by using electrical power routing in order to conceal the information of appliance usage.
Security and privacy	Information transmission	Attacks on data integrity(modification of information), network availability (DoS), information privacy(eavesdropping)	(Lu, Lu, Wang, & Wang, 2010)	Suggested that security attacks can beof three types: data integrity, network availability and information privacy.
			(Khurana, Bobba, Yardley, Agarwal, & Heine, 2010)	In power grid to ensure effectiveness and correctness of authentication they discuss engineering practices and key design principles.

Table 1 Performance Comparison of Various technologies for SG(Fang et al., 2012)

	Technology	Protocol	Range Km	Data rate Mbps	Network technology			Applications		Security	Scalability
					WAN	HAN	NAN	AMI	D/R		
Wired communication technology	DSL	HDSL VDSL ADSL	3.6 Km 1.5 Km 5 Km	2 Mbps 15-100 Mbps 1-8 Mbps	N	✓ ✓	✓ ✓ ✓	N	N	H	M
	Optical fiber	WDM SDH PON	100 Km 100 Km 60 Km	40Gbps 10Gbps 155-2.5Gbps	- - ✓	✓ ✓ ✓	✓ ✓ ✓	N	N	H	H
	Ethernet	802.3x	100m	10-10Gbps	✓	✓	✓	-	-	-	M
	Coaxial	DOCSIS	28 Km	172 Mbps	-	✓	✓	-	-	M	M
	PLC	Narrow band Home	3 Km 200m	10-500Kbps 14-200Mbps	- -	✓	✓	✓	-	M	M
Wireless communication technology	Wimax	802.16	50 Km	75 Mbps	✓	-	✓	✓	✓	M	M
	Wi-Fi	802.11x	100m	2-600Mbps	-	✓	✓	-	-	M	M-L
	ZigBee	ZigBee ZigBee Pro	100m 1600m	250Kbps 250Kbps	- -	✓	✓	✓	-	128-B AES	M-L
	Bluetooth	802.15.1	100m	721Kbps	-	✓	-	-	-	M	M-L
	Z-wave	Z-wave	30m	40kbps	-	✓	-	✓	-	128-B AES	M-L
	Satellite	Satellite internet	100-6000 Km	1Mbps	✓	N	N	-	-	L	M-L
	Cellular	4G	-	100Mbps	-	-	-	-	-	H	H
		3.5G	-	14Mbps	-	-	-	-	-	H	N
		3G	3-5 miles	2Mbps	✓	-	-	✓	✓	M	M
		2.5G	-	144Kbps	-	-	-	N	N	M	M
		2G	50Km	14.4Kbps	✓	-	✓	N	N	M	N
	Wireless Mesh	RF mesh, 802.11,802.15,802.16	Depend on deployment	Depend on protocol	-	✓	✓	N	N	M	M

5. CONCLUSION

In this paper, smart grid an advanced technology communication infrastructure as well as an overview of advanced meter infrastructure architecture is presented. As smart grid is considered to overcome the problems faced by existing grid as mentioned in introduction part but still it open many ways to cyber security threats as described in security and privacy section. There is still lot of work needed for secure used of smart grid as it is open to many cyber security threats so if smart grid has many applications on one side like self-healing property, improve quality etc. the second side of security cannot be ignored. The whole details about the smart grid motivation, applications, and also different communication technologies that are used in different features of smart grid are explained in this paper. The whole details about smart grid applications, motivation for SG, communication in SG, security and privacy presented in this paper are collected from different papers and merged them into one. At the end still lot of work needed for implementing smart grid securely.

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