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SMART GRID SYSTEMS IN INDIAN POWER SECTOR AN OVERVIEW

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ABSTRACT

Optimization of energy consumption in future intelligent energy networks (or Smart Grids) will be based on grid-integrated near-real-time communications between various grid elements in generation, transmission, distribution and loads.

This paper discusses Smart Grid (SG) in India and opportunities seen with the formal launch of Digital India Project in the areas of smart grid and smart metering. In particular, we focus on some of the key communications challenges for realizing interoperable and future proof smart grid/metering networks, smart grid security and privacy, and how some of the existing networking technologies can be applied to energy management. Finally, we also discuss the coordinated standardization efforts made by Government of India to harmonize communications standards and protocols.

Index Terms: Smart Grid, Smart Metering, Demand Response, Interoperability, Standards, Wireline and Wireless Communications, Renewable Energy, Security, Privacy.

I. INTRODUCTION

While the legacy grid has served well for the last century or so, there is a growing need to update it in India, from the points of view of both the aging infrastructure and the new environmental and societal challenges. As a result, national governments and relevant stakeholders are making significant efforts in the development of electrical grids to Smart Grids. Unlike in legacy power systems, the smart grid implements a two way communications model which acts as an enabler for novel services such as smart metering and demand response systems [1]. Smart Grids also facilitate the two way flow of energy. A smart grid is an intelligent electricity network that integrates the actions of all users connected to it and makes use of advanced information, control, and communications technologies to save energy, reduce cost and increase reliability and transparency. Development of this smart grid requires significant efforts in technology development, standards, policy and regulatory activities due to its inherent complexity.

A proper demand management through the smart grid technology has the potential to yield significant savings in the generation and transmission of energy. This is mainly due to the reduction of number of peaker plants needed to cater for peak demand that occurs only a small percentage of time.

Many countries are currently making massive investments on smart grid research and development.

India's Smart Grid policy is an emerging part of its nationwide energy policy. The policy is being jointly developed by a collaborative grouping of central and state governmental bodies and subject matter experts from industry, academia and non-governmental research and development organizations.

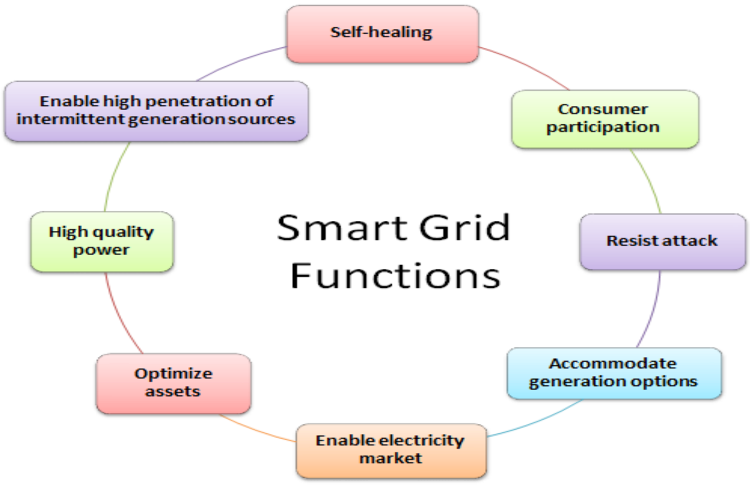
By analyzing the growing power demand and market competence, this seems to be the only way-forward for the domestic power industry. The biggest concern in implementation of Smart Grid in India is a number of issues such as minimizing T&D losses, power theft, inadequate grid infrastructure, low metering efficiency and lack of awareness[2].

The government of India through the technology development platform has established a carefully planned approach to the implementation of smart grid technologies in the medium to long term. Establishing work on standardization, research projects involving academia with industries (utilities and manufacturers), and demonstration/pilot projects are the current priority[3].

Smart grids and smart metering are expected to contribute significantly towards improving energy usage levels through the following four mechanisms[1]:

• Energy feedback to home users through an IHD (In-Home Display) - Accurate energy consumption, coupled with real-time pricing information is expected to reduce energy usage within the home; especially as energy prices continue to rise.

• Energy consumption information for building operators -to assist with the detailed understanding and optimization of energy requirements in buildings.



• The inclusion of distributed micro-generation based on locally-distributed clean, renewable energy sources such as wind and solar.

• Real-time demand response and management strategies for lowering peak demand and overall load, through appliance control and energy storage mechanisms (including electrical vehicles).

To enable the above functionalities, an effective, reliable, and robust communication infrastructure has to be in place.

This paper provides an overview of the following important issues of smart grid communications: communication infrastructure, network architecture, demand response management, security and privacy challenges, and standardization activities. Compared to other recent surveys on smart grid (e.g. [8] and [9] which are mainly from an academic perspective) , our primary aim is to provide a coherent picture of the current status of smart grid communications, especially focusing on research challenges, standardization, and industry perspectives keeping in mind the recent Digital India initiative by Government of India .

Digital India initiative of Government of India aims at ensuring the government services are made available to citizens electronically by reducing paperwork. The initiative also includes plan to connect rural areas with high-speed internet networks. Digital India has three core components [2]. These include (a)The creation of digital infrastructure, (b)Delivering services digitally (c)Digital literacy.

A two-way platform will be created where both the service providers and the consumers stand to benefit. The scheme will be monitored and controlled by the Digital India Advisory group which will be chaired by the Ministry of Communications and IT[3,4]. The Public-private-partnership model shall be adopted selectively. In addition, there are plans to restructure the National Informatics Centre. Top corporates have pledged investments of Rs. 4.5 lakh crore for initiatives of project 'Digital India' [5].

We would like to point out that since the smart grid is a vast area, the main focus of this paper is on smart grid communications with reference to Digital India initiative. For overviews on other aspects of smart grid, e.g. technologies on the transmission side and control center of the smart grid please refer to [10] and [11].

In order to perform all of these operations, the smart grids consist of a control center located inside the utility grid, a billing center that collects the bills, a number of smart energy meters distributed among buildings, and a communication infrastructure.

Furthermore, this article mainly provides a technical perspective of the smart grid. For a business or economic perspective, the readers are referred to [12].

In this paper the current state in smart grid security is surveyed. How Digital India initiative by Government of India aims at ensuring to plug in the Challenges faced in the implementation of Smart Grid. The rest of the paper is organized as follows. Section-2 describes the smart information subsystem used to support information generation, modeling, integration, analysis, and optimization in the context of the SG. Section-3 presents the smart infrastructure system is the smart communication subsystem. This smart communication is responsible for communication connectivity and information transmission among systems, devices, and applications in the context of the SG. Section-4 presents the development needed in the fields described in the previous Section. It also presents the Digital India Initiative in context of SG, challenges and seriousness of Government of India to this paradigm shift. Mentioned also is the outline of some future research directions and challenges.Section-5 concludes the paper.

II. SMART INFORMATION SYSTEM

In this section, we concentrate on the smart information and smart communication subsystem. We first explore the information metering and measurement, which generates information from end entities (e.g., smarter meters, sensors, and phasor measurement units) in an SG. This information is often used for billing, grid status monitoring, and user appliance control. We then explore the information management, including data modeling, information analysis, integration, and optimization.

2.1 Information Metering and Measurement

Study in information metering and measurement can be classified into smart metering, and smart monitoring and measurement [13]. The smart monitoring and measurement can be also divided into sensor and Phasor Measurement Unit (PMU) [3] -[5].

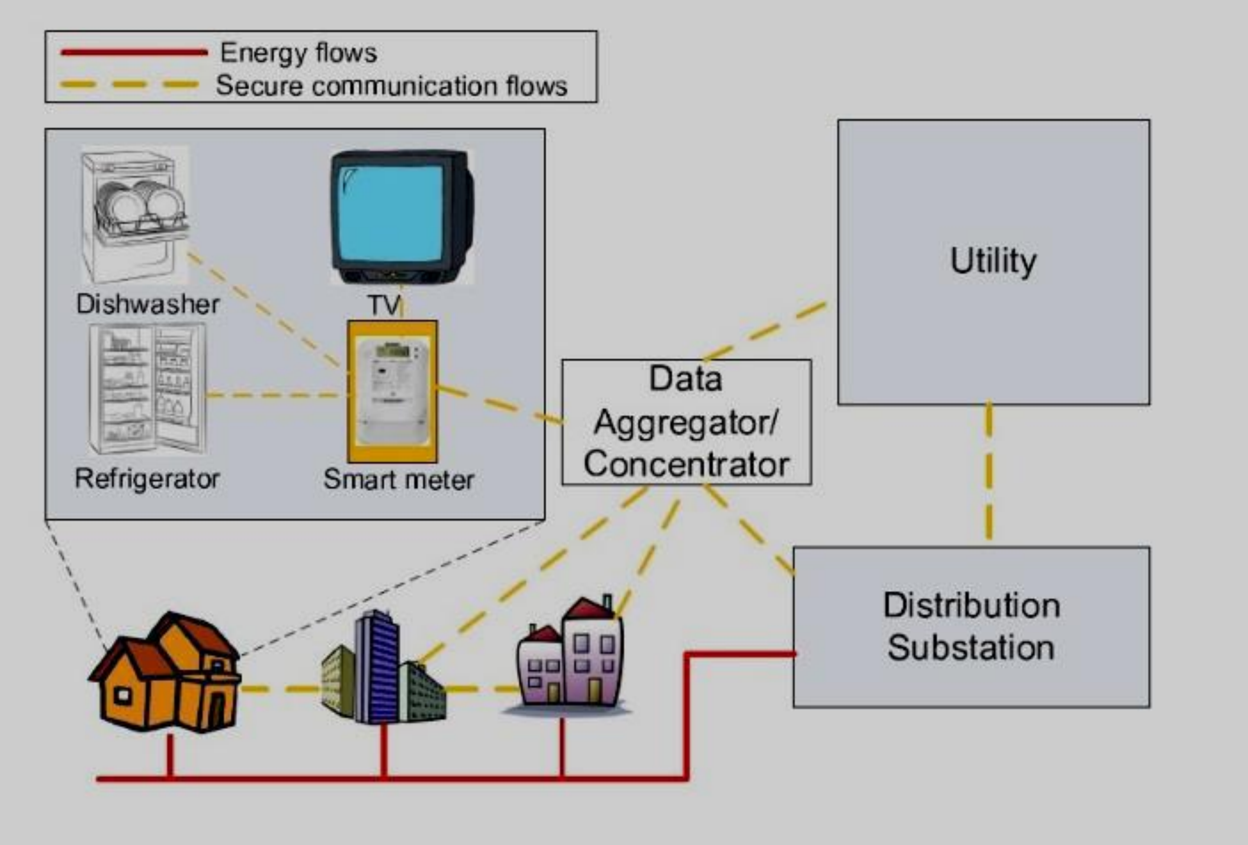


Figure 1. An Example of the Smart Metering Structure

2.1.1 Smart Metering

Smart metering is the most important mechanism used in the SG for obtaining information from end users' devices and appliances, while also controlling the behavior of the devices. Smart meters, which support two-way communications between the meter and the central system, are similar in many aspects to Automatic Metering Infrastructure (AMI) meters, or sometimes are regarded as part of the AMI. A smart meter is usually an electrical meter that records consumption in intervals of an hour or less and sends that information at least daily back to the utility for monitoring and billing purposes [13]. Also, smart meters have the ability to disconnect -reconnect remotely and control the user appliances and devices to manage loads and demands within the future smart-buildings." Figure 1 shows a typical usage scenario for smart meters. The smart meter collects the power consumption information of the dishwasher, TV, and the refrigerator, and also sends the control commands to them if necessary. The data generated by the smart meters in different buildings is transmitted to a data aggregator. This aggregator could be an access point or gateway. This data can be further routed to the electric utility or the distribution substation. Note that the smart communication subsystem has been described in second this paper, is responsible for the information transmission. From a consumer's perspective, smart metering offers a number of potential benefits. For example, end users are able to estimate bills and thus manage their energy consumptions to diminish bills. From a utility's viewpoint, they can use smart meters to realize real-time pricing, which tries to encourage users to reduce their demands in peak load periods, or to optimize power flows according to the information sent from demand sides.

2.1.2 Smart Monitoring and Measurement

An important function in the vision of SG is monitoring and measurement of grid status. We review the following two major monitoring and measurement approaches, namely sensors and phasor measurement units.

Sensors: Sensors or sensor networks have already been used as a monitoring and measurement approach for different purposes [14]. In order to detect mechanical failures in power grids such as conductor failures, tower collapses, hot spots, and extreme mechanical conditions. Sensor networks should be embedded into the power grid and help to assess the real -time mechanical and electrical conditions of transmission lines, obtain a complete physical and electrical picture of the power system in real time, diagnose imminent as well as permanent faults, and determine appropriate control measures that could be automatically taken and/or suggested to the system operators once an extreme mechanical condition appears in a transmission line.

Wireless sensor networks (WSNs) in particular, given their low cost, can provide a feasible and cost- effective sensing and communication platform for remote system monitoring and diagnosis. However, the use of sensor networks in the SG has many requirements [15-16]such as Quality-of-Service (QoS) requirements, Resource constraints, Remote maintenance and configuration, High security requirements and Harsh environmental conditions.

Phasor Measurement Unit (PMUs) help create a reliable power transmission and distribution infrastructure [17]. A PMU measures the electrical waves on an electrical grid to determine the health of the system. Technically speaking, a phasor is a complex number that represents both the magnitude and phase angle of the sine waves found in electricity. Phasor measurements that occur at the same time are called synchrophasor, as are the PMU devices that allow their measurement. Typically, PMU readings are obtained from widely dispersed locations in a power system network and synchronized using the global positioning system (GPS) radio clock. With a large number of PMUs and the ability to compare shapes from alternating current (AC) readings everywhere on the grid, system operators can use the sampled data to measure the state of the power system and respond to system conditions in a rapid and dynamic fashion [18].The installation of PMUs on transmission grids of most major power systems has become an important activity.

2.2 Information Management

In SG, a large amount of data and information will be generated from metering, sensing, monitoring etc. SG must support advanced information management. The task of the information management is data modeling, information analysis, integration and optimization.

2.2.1. Data Modeling

As stated by IEEE P2030 [28], the goal of SG information technology data modeling is to provide a guide to creating persistent, displayable, compatible,

transferable, and editable data representation for use within the emerging SG. In other words, the objective is to make it as interoperable as possible using relevant standards. That is specifically addressing the data that represents state information about the grid and individual items in it.

2.2.2 Information Analysis, Integration and Optimization

Information analysis is required to support the processing, interpretation and correlation of the flood of new grid observations, since the widely deployed metering and monitoring systems in SG will generate a large amount of data for the utility. One part of the analytics would be performed by existing applications, and another part of the analytics dimension is with new applications and the ability of engineers to use a workbench to create their customized analytics dashboard in a self-service model [28].

Information integration aims at the merging of information from different sources with different conceptual, contextual and typographical representations. In SG, a large amount of information has to be integrated.

Information optimization is used to improve information effectiveness. The data size in the future SG is anticipated to be fairly large as a result of the large-scale monitoring, sensing and measurement. However, the generated data may have a large amount of redundant or useless data. Therefore, the advanced information technology is required to improve the information effectiveness, in order to reduce communication burden and store only useful information. In order to compress the size of disturbance signals and reduce sinusoidal and white noise in the signals, a wavelet -based data compression approach has been proposed for SG [19].

III. SMART COMMUNICATION SYSTEM

This subsystem is responsible for communication connectivity and information transmission among systems, devices and applications in the context of the SG. In this section, the smart communication subsystem in SG has been overviewed. Then the wireless and wired communication technologies are discussed subsequently.

Figure 2 shows an example of a communication network used in SG. User devices and smart meters use ZigBee, Wi-Fi, and powerline communications. Wireless mesh networks are used for information exchanges between users. Communities are connected to their electric utility via free-space optical, satellite, microwave, or cellular systems. A substation communicates with an electric utility over the powerline.

3.1 Wireless Technologies

Wireless technologies not only offer significant benefits over wired technologies, such as low installation cost, rapid deployment, mobility, etc., but are also more suitable for remote end applications. Wireless has already been widely used in our daily life and can be deployed anywhere and anytime. The following important wireless communication and networking technologies may be applicable in future SG.

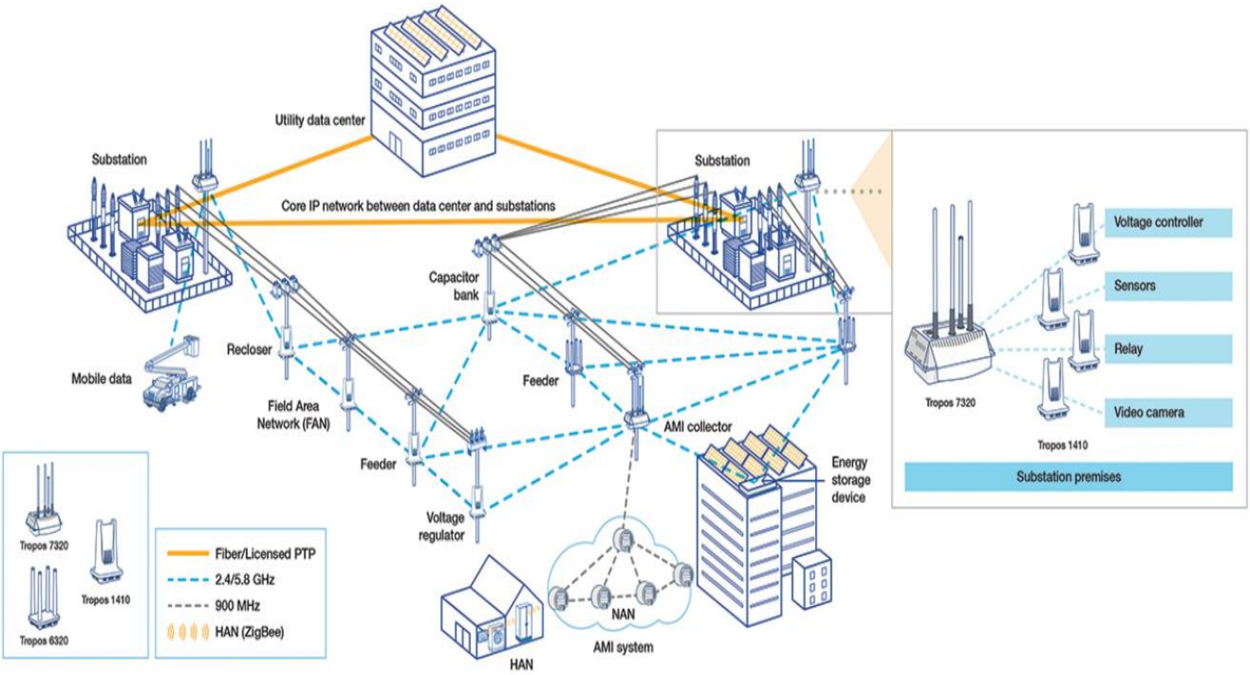


Figure 2. An Example of a Communication Network used in SG

3.1.1 Wireless Mesh Network

Wireless mesh network (WMN), which is a communication network made up of radio nodes organized in a mesh topology, has developed as a key technology for next - generation wireless networking. Industrial standards groups, such as IEEE 802.11 and802.16 are all actively working on new specifications for WMNs. A WMN also offers basic networking infrastructure for the communications in SG. Some of the benefits of using WMNs in SG are highlighted as follows:

- Increased communication reliability and automatic network connectivity
- Large coverage and high data rate

3.1.2 Cellular Communication Systems

A cellular communication system, such as GSM and 3G (WCDMA and CDMA-2000), is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver known as a cell site or base station. It has been a proven mature technology for data transmission for several decades. By using the existing 3G (or even 4G) cellular communication systems, it is quick and inexpensive to obtain data communications coverage over a large geographic area [20].Researchers have also conducted some studies on cellular communications for the SG. For example, a new network model in which sensor/relay nodes can also communicate with other back-end nodes using a wide area network such as the cellular network, and proved that the delay and cost of transmitting data can be reduced [21].

3.1.3 Cognitive Radio

The communication system in SG needs to be designed to accommodate the current management requirements as well as the potential demand of future applications. It is likely that unlicensed spectrum will also be used when SG is in large-scale commercial use.

3.1.4 Communications based on 802.15.4

Three wireless communication technologies based on IEEE 802.15.4 protocol stack are recommended to be used in SG [23]. Which are ZigBee, Wireless HART, and ISA100.11a. ZigBee is a wireless technology which is planned for radio-frequency applications that require a low data rate, long battery life and secure networking.

3.1.5 Satellite Communications

Satellite communication is a good solution for remote control and monitoring, since it delivers global coverage and rapid installation [22]. In some scenarios where no communication infrastructure exists, especially for remote substations and generation deployments, satellite communication is a cost-effective solution. However, it would be noted the disadvantages of satellite communications. There are two major limitations. First, a satellite communication system has a substantially higher delay than that of a terrestrial communication system. This makes some protocols (e.g., TCP), which are originally designed for terrestrial communication, unsuitable for satellite communications [15]. Second, satellite channel characteristics vary depending on the effect of fading and the weather conditions. This property can heavily degrade the performance of the whole satellite communication system [23].

3.1.6 Microwave or Free-space Optical Communications

Microwave technologies are widely used for point -to-point communications, since their small wavelength allows use of conveniently sized directional antennas to obtain secure information transmission at high bandwidths. Free-space optical communication is an optical communication technology that can use light broadcasting in free space to transmit point-to-point data. It allows high bit rates with low bit error rates.

However, both microwave communication and free-space optical communication are line of sight (LOS) communication technologies. Therefore, their communication qualities are greatly affected by obstacles (e.g., buildings and hills) and environmental constraints (e.g., rain fade).

3.2 Wired Technologies

It is also assumed that wired communication technologies would be integrated into SG. The important wired communication technologies are given below.

3.2.1 Fiber-optic Communications

Due to its high bandwidth capacity and invulnerability characteristics, it is supposed that optical fibers would play an important role for the information network backbones in future SG [15]. Although it is well-known that the installment cost of optical fibers may be expensive, fiber optic network is still a cost -effective communication infrastructure for high speed communication network backbones in future SG, since such fibers are already widely deployed in today’s communication network backbones, with a large amount of spare capacity being unused.

Powerline Communications: Powerline communications (PLC) is a technology for carrying data on a conductor also used for electric power transmission. In the last decades, utility companies around the world have been using PLC for remote metering and load control applications. The debate on what is the actual role of PLC in future SG is still open. Some advocate that PLC is very good candidates for some applications, while others express concerns on PLC (e.g., the security issue due to the nature of powerlines) [24].

3.3 End-to-end Communication Management

One important issue in the communication subsystem is the end-to-end communication management. More specifically, in this heterogeneous communication subsystem where various communication technologies, network structures, and devices can be used, it is required to identify each entity and solve the problem of how to manage end-to-end communications. Recently, there is a growing trend towards the use of TCP/IP technology as a common and consistent approach in order to achieve end-to-end communications [25]. National Institute of Standards Technology (NIST) also indicated that there are a number of benefits that make TCP/IP an important SG technology, including the maturity of a large number of standards, the availability of tools and applications that can be applied to SG environments and its widespread use in both private and public networks [26].

IV. FUTURE RESEARCH DIRECTIONS AND CHALLENGES

4.1 Future Research on Smart Communication System

In this section, the work on the smart communication subsystem, including wireless technologies, wired technologies and end-to-end communication management are reviewed consequently. The challenges and possible directions worth exploring of smart communication system are also enlisted.

(i)Interoperability of communication technologies: Since many different communication protocols and technologies would be advised in SG and each of them probably can be its own protocols and algorithms, materializing interoperability is not easy. Although the framework architecture in the classic layer model of Open Systems Interconnection could provide a promising conceptual solution to this problem, it is well -known that this model suffers in some modern applications.

(ii)Dynamics of the communication subsystem: The communication subsystem underlying an SG can be dynamic, with topology changes being unpredictable. For example, both the operation of connecting (or disconnecting) the electric vehicle (EV) to (or from) the grid and the motion of vehicle may result in the change of communication network topology.

(iii)Smoothly updating existing protocols: The current power grid has used several protocols to realize simple data communications. For example, the currently used metering and Supervisory Control and Data Acquisition Systems (SCADA protocols are based on a simple request/response scheme with their own addressing [25]. One problem is how to smoothly update existing protocols to the ones which are applicable in future SG.

4.2 Future Research on Smart Information System

In this section, the work on the smart information subsystem has been reviewed, especially information metering, measurement and management in SG. Then the following challenges and possible directions worth exploring are enlisted.

(a)Effective information store: A large amount of information, such as the data from smart meters, sensors and PMUs will be sampled in SG and sent to the control system. One vital problem is what information should be stored in the control system so that meaningful system or user history can be constructed from this data. Note that system history is important for analyzing system operations and user history is important for analyzing user behaviors' and bills.

(b)The utilization of cloud computing: Cloud computing has been intended as the next-generation computing paradigm for its major advantages in on-demand self-service, universal network access, location independent resource pooling and transference of risk [27]. The basic idea of the cloud computing is that the cloud providers, who operate large data centres with enormous computation and storage capacities, deliver computing as a service, whereby shared resources, software and information are provided to computers and other devices as a utility over a network. Integrating cloud computing may improve the information management in SG. First, since cloud providers have massive computation and storage capacities, they can design some basic and generic information management services for electric utilities. Second, cloud computing may be able to improve the information integration level in SG.

4.3 The Digital India initiative is commendable and deserves full support of all stakeholders. However, the initiative also lacks many crucial components including lack of legal framework, absence of privacy and data protection laws, civil liberties abuse possibilities, lack of parliamentary oversight for e-surveillance in India, lack of intelligence related reforms in India, insecure Indian cyberspace, etc. These issues have to be managed first before introducing DI initiative in India. Digital India project is worth exploring and implementation despite its shortcomings that can be rectified before its implementation.[2]

Challenges Before Digital India: The Government of India entity Bharat Broadband Network Limited which executes the National Optical Fibre Network project will be the custodian of Digital India (DI) project. BBNL had ordered United Telecoms Limited to connect 250,000 villages through GPON to ensure FTTH based broadband. This will provide the first basic setup to achieve towards DI and is expected to be completed by 2017.

The Digital India initiative is a promising initiative of the Indian Government. Many companies have shown their interest in this project.[3] It is also believed that E-commerce would facilitate the DI project. However, it is not free from challenges and legal hurdles. Some believe that DI cannot be successful till mandatory e-governance services in India are introduced. Having incomplete implementation of the National e-Governance Plan of India will only affect the success of the DI project. India has poor regulations in the field of privacy protection, data protection, cyber law, telegraph, e-governance, e-commerce, etc. Further, many legal experts believe that e-governance and DI without cyber security is useless.[6] The cyber security trends in India [7] have exposed the vulnerability of Indian cyberspace. Even the National Cyber Security Policy 2013 has not been implemented till now. In these circumstances, Critical infrastructure protection would be a really tough task to manage for the Indian Government. The project also lacks the concept of proper E-waste management.

Related Initiatives: The DI initiative must be read along with the Draft Internet of Things (IoT) Policy of India. However, the problems, the challenges and the deficiencies in the Indian legal structure remain the same.

Civil Liberties Issues: Initiatives like DI and IoT would be required to comply with the Civil liberties requirements in general and civil liberties protection in cyberspace in particular. India has not given any importance to privacy and privacy laws so far. Indian government indulges into Mass surveillance in India and projects like Aadhaar, Central Monitoring System, Netra, NATGRID, etc. are operating without any law and parliamentary oversight. The intelligence agencies of India like Intelligence Bureau and law enforcement agencies like Central Bureau of Investigation are operating for decades without any law and parliamentary scrutiny. DI and IoT would further strengthen the mass surveillance activities of the Indian Government if proper procedural safeguards are not implemented and practiced.

Status of Digital India: Digital India is in the progress mode till the month of November 2014. The Apex Committee is going to analyze its progress very soon.[4] Media reports have also hinted at development of policies for Digital India very soon. If correctly implemented, Digital India project can change the age old legacy grid and the Power transmission and distribution system in India in the near future.[2]

V. CONCLUSION

In this paper we have presented an overview of the unique challenges and opportunities posed by smart grid communications, e.g. interoperability, new infrastructure requirements, scalability, demand response, security and privacy. The success of future smart grid depends heavily on the communication infrastructure, devices, and enabling services and software.

Results from much existing communications research can be potentially applied to the extremely large-scale and complex smart grid, which will become a killer application. In parallel to technical issues of smart grids, we have also discussed the current status of standardization on smart metering in Digital India.

It is very desirable to have a single set of standards defining the interfaces, communications and data exchange formats for smart metering and smart grids. For different energy supply companies, the timely harmonization of the many existing standards with the new additional functionality requirements will be very difficult. It is very important that the activities are aligned and take into account these requirements, and reflect them well at international standardization activities.

Although the roadmap of smart grid deployment is still not clear, it is almost certain that the future intelligent energy network empowered by advanced ICT technology will not only be as big as the current Internet, but also change people's lives in a fundamental way similar to the Internet.

As communication is an underpinning technology for this huge development, we envisage that smart grids will be an exciting research area for communication engineers for many years to come.

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