Role of smart grid in power sector and challenges for its implementation: A review on Indian scenario

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In recent years, smart grid (SG) is increasingly recognized and undergoing trial and testing in the power sector of both developed and developing countries. SG consists of many advanced technologies to address many issues in conventional electricity networks but faces challenges in adoption and implementation. This paper focuses on the challenges for smart grid implemetation in India.The Government of India (GoI) under National Smart Grid Mission (NSGM) has initiated the establishment of the institutional set ups and implementation of pilot projects for the development of smart grids in the country. The main challenges to adopt smart grid technology like interoperability, integration with existing systems, lack of skill and consumer engagement, testing facilities for smart meters and adoption of smart grid regulations were identified. The GoI is making efforts to initiate different strategies to overcome all the above mentioned challenges for the widespread implementation of smart grids to meet future energy demand in reliable and efficient way.

Keywords:

Energy sources distribution, smart grid technology, implementation, challenges.

1. Introduction

India is one of the fastest developing South Asian countries with 1.36 billion population. To meet the energy needs of the growing population, GoI adopted different policies and implemented various projects in the energy sector of India, particularly in power and electricity. India's e share of global energy consumption is 3.4% and, is ranked 5th an 6th in electricity generation and power capacity globally (S. Kumar, Sep 2014).

The annual national energy demand in India by 2050, will be 14,500 TWh with a Compound Annual Growth Rate (CAGR) of 6.7 % (Sambit Nayak, 2017). Industrialization, growing population, rising employment and income, and increasing living standards are driving the 3.6 % pa growth in India's energy consumption (S. Kumar, Sep 2014). The total installed capacity of electricity generation in increased from 168,048 MW to 377,122 MW with a CAGR of 8.42% (Ofiice, 2018). The l installed electricity generation capacity by type of energy source in India (per the Ministry of Power, GoI records) is shown in Fig 1 (*Executive summary of power sector for month of January-2017*, 2018). 60% comes from coal, but India has enormous renewable energy potential for power genertaion like solar, wind, biomass, small hydro and cogeneration of baggase.

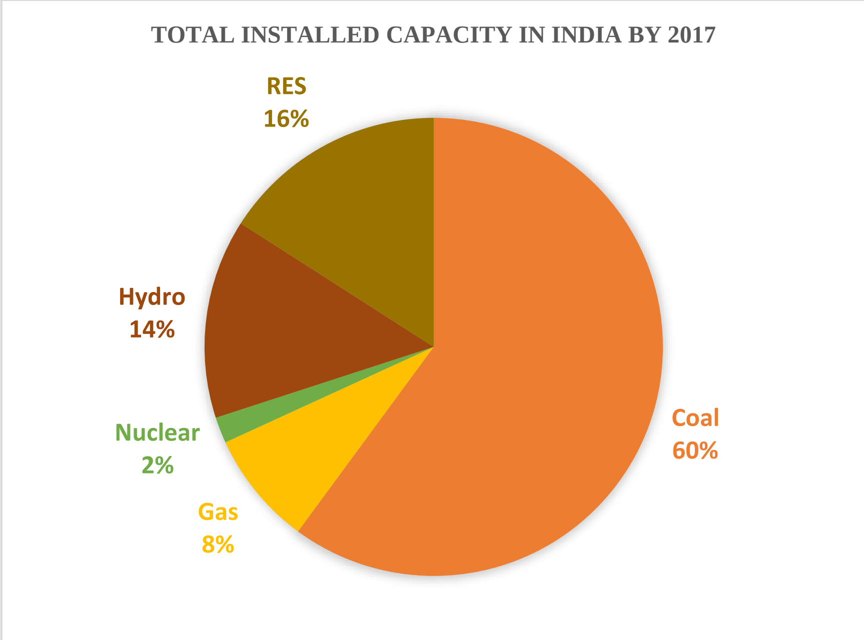

Fig. 1 Electricty generation by Source in India-2017.

The five regional grids in India were connected as a single national grid on 31st December 2013 under the mission of "One Nation One Grid" by "Power Grid Corporation of India" after the massive blackout that happened in December 2012 in North Inida (*One Nation- One Grid*, December 2016). The two-day blackout affected almost 300 million people (this was about 9% of the world population) (Sujay Mehuddia, 2012). After the huge massive blackout, GoI took necessary steps not only to integrate all the regional grids into a single national grid but also, to e install more on-grid and off-grid renewable energy power plants. The installed on-grid and off-grid renewable energy plant capacities in Indiaa by 2017 are shown in Table 1 ("Year End Review 2017 - MNRE," 2017) .

Table 1 On grid and off grid renewable energy sources capacities in India by 2017.

Source	On grid capacity (MW)	Source	Off grid capacity (MW)
Wind	32746.87	Waste to energy	175.45
Solar	16611.73	Biomass cogeneration	661.41
Small hydro power	4399.35	Biomass gasifiers	163.37
Bio power	8181.70	Aerogenerators/Hybrid	3.29
Waste to power	114.08	SPV systems	551.56

Installation and integration of new generation plants, availability and reliability of resources, inadequate plant equipment and maintanance, land acquisition and environmental issues, man power shortages, theft of power, and lack of intra-day load estimation curves are some of the key challenegs in the existing electricity grid of India (Dubey, 2015). Smart grids use bidrectional information management technology, done through Internet of Things (IoT), can help solve most of the issues in exisiting conventional grid of India.

2. Structure of Smart Grid networks

Smart Grids (SG) are designed to be e self sufficient andreliable electricity networks which can handle the problems of existing conventional grid to ensure reliable, safe and quality of electricty to all electricity consumers (Bayindir, Colak, Fulli, & Demirtas, 2016).

2.1 Smart Grid definitions

Smart Grid can be defined as the integration of information and communication technology into the electricity transmission and distribution network. In other words, smart grid is "an automated, widely distributed energy delivery network characterized by a two-way flow of electricity and information, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances".

The National Institute of Standards and Technology (NIST), USA defined smart grid as a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications. As per the Institute of Electrical Electronic Engineers (IEEE), smart grid is a large system of systems, where each functional domain consists of three layers namely; power and energy, communication and Information Technology (IT or computer layer). Communication and IT layers are the enabling infrastructures that makes the existing power and energy layer "smarter" (Chakrabarti).

2.2 Characteristics of SG networks

SGs have the following important characteristics to work as a self-sufficient network (Chakrabarti; Hamilton, 2010).

1. SG enables the active participation of the consumers by increased communication with grid that benefit both the grid and environment.
2. SG enables effective integration of power generation system from diverse energy sources
3. SG allows a grid to have a wide geographical spread due to large distances between power generation sources and load centers.
4. SG enables new products, services and markets which results from the increase in population and standard of living, and the development of townships.
5. SGs allows provision of quality power in digital device environments that avoid production and productivity losses.
6. SGs enables larger numbers of interconnections even if there are exisitng or possible political, economical, environmental, reliability and stability issues.
7. SG optimizes asset utilization and operates efficiently through targeted and efficient maintenance programs.
8. SG can anticipate and respond to system disturbances and can restore the grid components and the network faster.
9. SGs involves real time monitoring and needs strict regulation for effective implementation and operation.
10. SGs can have operational resiliency that can protect the grid from terror attacks and natural disasters, thereby contributing to improving public safety.

The structure of existing conventional grid and smart grid electricity networks are shown in Fig.2. The different technologies used in SG networks for its effective operation, as shown in Fig.2 are as follows (Hamilton, 2010):,

- Advance Metering Infrastructure (AMI)
- Transmission Enhancement Applications (TA)
- Customer side Systems (CS)
- Demand Response (DR)
- Distribution Management System/Distribution Automation (DMS)
- Transmission Enhancement Applications (TA)
- Asset/System Optimization (AO)
- Distributed Energy Resources (DER)

- Information and Communications Integration (ICT).

Fig. 3. shows the mapping network needed for the improvement of six SG characteristics, such as: reliability, economics, efficiency, environment, safety, security by implementing the above mentioned SG technologies (Hamilton, 2010).

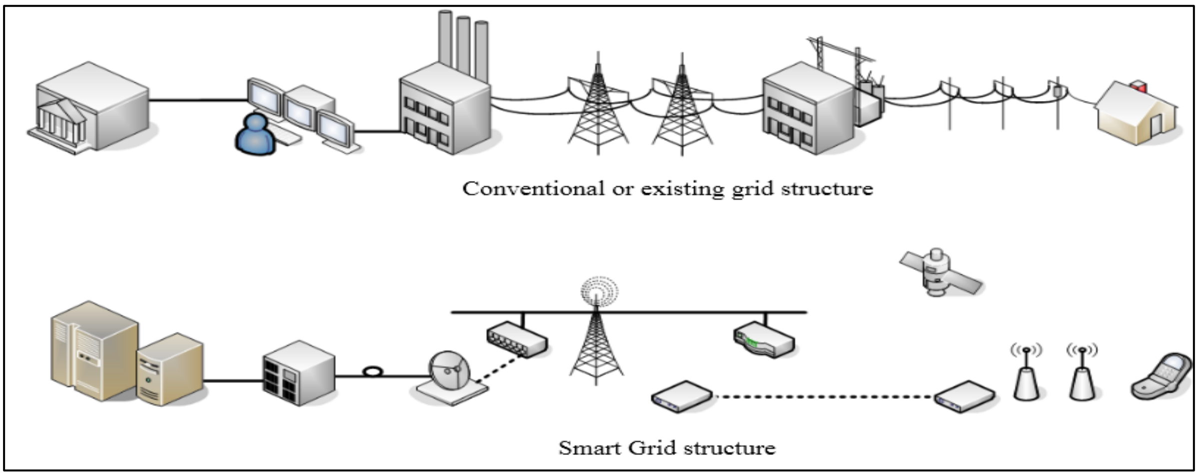

Fig. 2 Structure of conventional and smart grids.

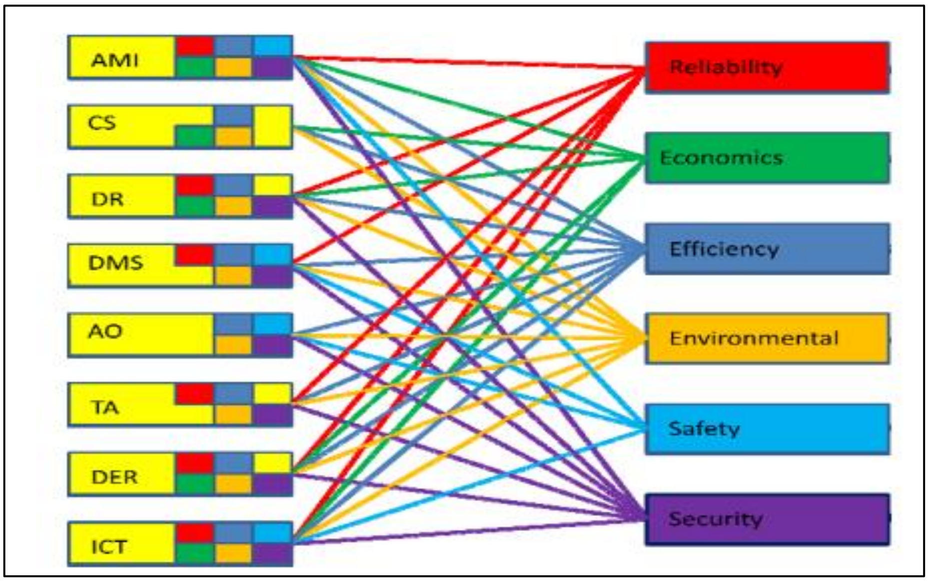

Fig. 3 Mapping of SG technology with its characteristics.

In all the different technologies used in SGs, AMI is an important technology as it is use for smart metering and monitoring of two-way communication between the grid and the electricity consumers. This two-way communication in SG, from the generation point to the customer, is shown in Fig. 4.

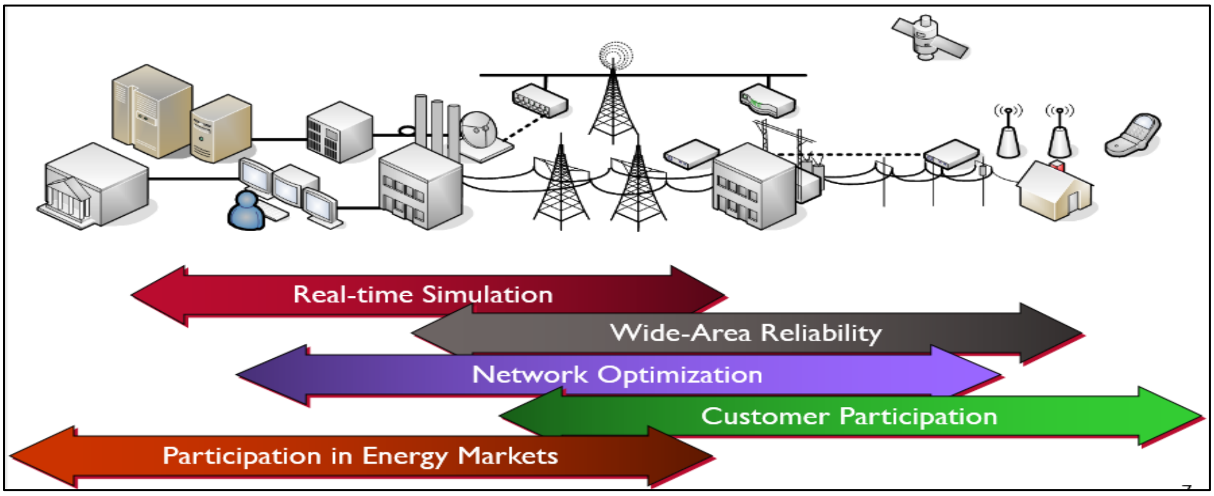

Fig. 4 The possible two-way communication in smart grid.

2.3 Benefits of smart grid

The implementation of SGs in India's electric grid can benefit the following three sector, (Li Chao, 2011)

- Utilities
- Regulators
- Customers

The benefits to these three sectors are shown in Fig. 5 below (Li Chao, 2011).

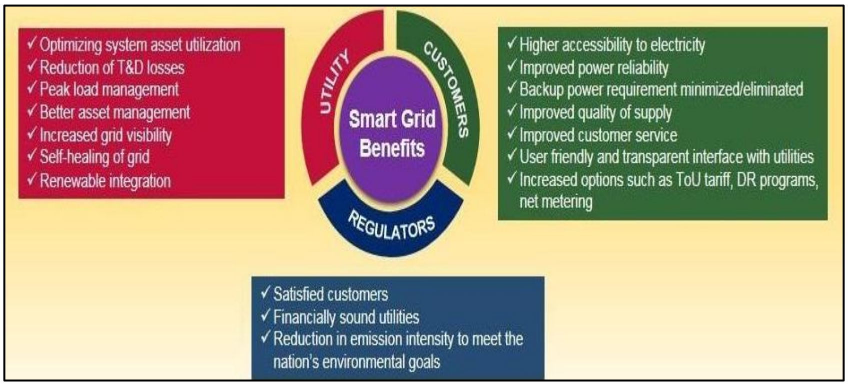

Fig. 5 Benefits of smart grid.

3. Pilot projects for SG by GoI

The GoI, through the Union Power Ministry, launched a nonprofit consortium named as Indian Smart Grid Forum (ISGF) for the development of SG technologies in the Indian power sector on May 26, 2010. The Indian Smart Grid Task Force (ISGTF), the governmental focal point, was also established to monitor the activities related to the development of SG technologies. ISGF and ISGTF were formed as the active branches of the National Smart Grid Mission, Ministry of Power (MoP)(Chakrabarti; Li Chao, 2011).

Several pilot projects were initiated in major cities of India by MoP and the Ministry of Urban Development. Energy providers, policy makers, regulation authorities and enterprises are the different participating entities in SG. They are involved in the operations of the different parts of power grid like generation, transmission, and distribution. Electricity customers are also considered as another important SG entity. The description of SG entities is shown in Fig. 6.

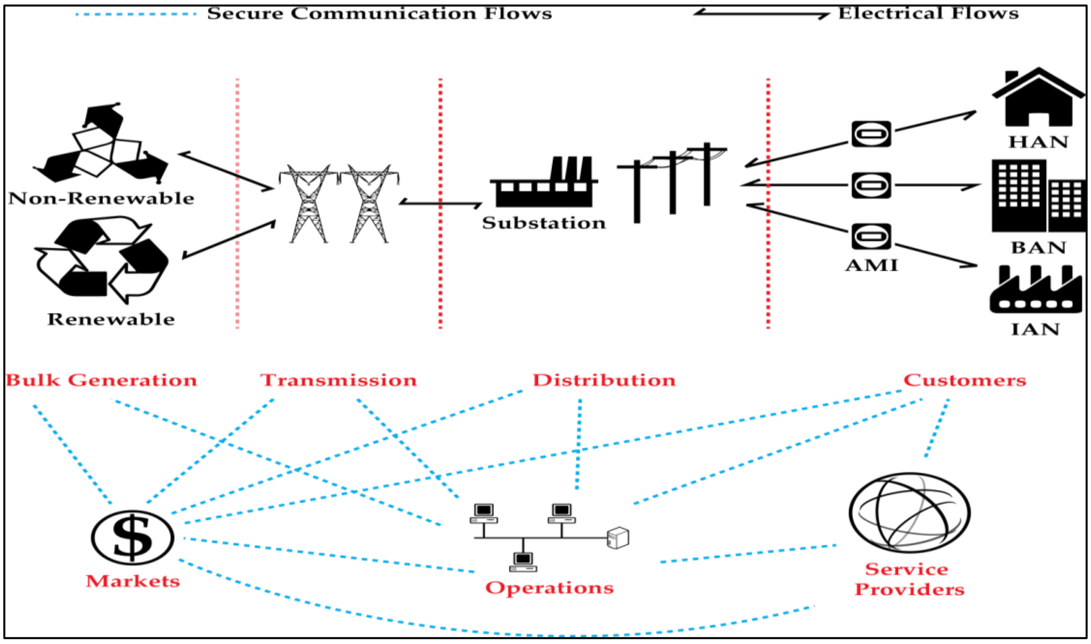

Fig. 6 Description of SG entities.

3.1. National Smart Grid Mission (NSGM)

The GoI approved the establishment of the NSGM in the power sector on March 27, 2015 (Li Chao, 2011). The NSGM is to plan, monitor and implement the policies and programmes related to Smart Grid activities in India. The NSGM was given its own resources, authority, and functional & financial autonomy.

The NSGM - Project Management Unit (NPMU) is housed in POWERGRID as the single point of contact on GoI's views on Smart Grid (Li Chao, 2011). The total budgetary outlay for NSGM activities for the India's 12th Plan is about 9.8 billion INR.

NSGM has a three-tier structure, starting from the Ministry of Power to the utilities. The complete structure of NSGM is shown in Fig. 7 (Li Chao, 2011). Tier – I, is the governing council from MoP, Tier- II has empowered committee and technical committee from MoP and Tier – III has NSGM and the bodies that work through NSGM. Under these three tiers, the activities of SG are taken of by state level project management units under the direction of the state power ministries.

3.2 Scope and vision of NSGM

Smart Grid vision of India: **"**Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders" (Li Chao, 2011).

Scope of NSGM:

1. Deployment of smart meters and AMI.
2. Substation renovation and modernization with deployment of gas insulated sub-stations (GIS).
3. Development of distributed generation in form of roof top PVs.
4. Real-time monitoring and control of DTs.
5. Provision of harmonic filters and other power quality improvement measures.
6. Creation of EV charging infrastructure for supporting proliferation of EVs.
7. Development of medium-sized micro-grids.

The developments in NSGM in the Indian power sector is shown in Fig. 8 (Li Chao, 2011).

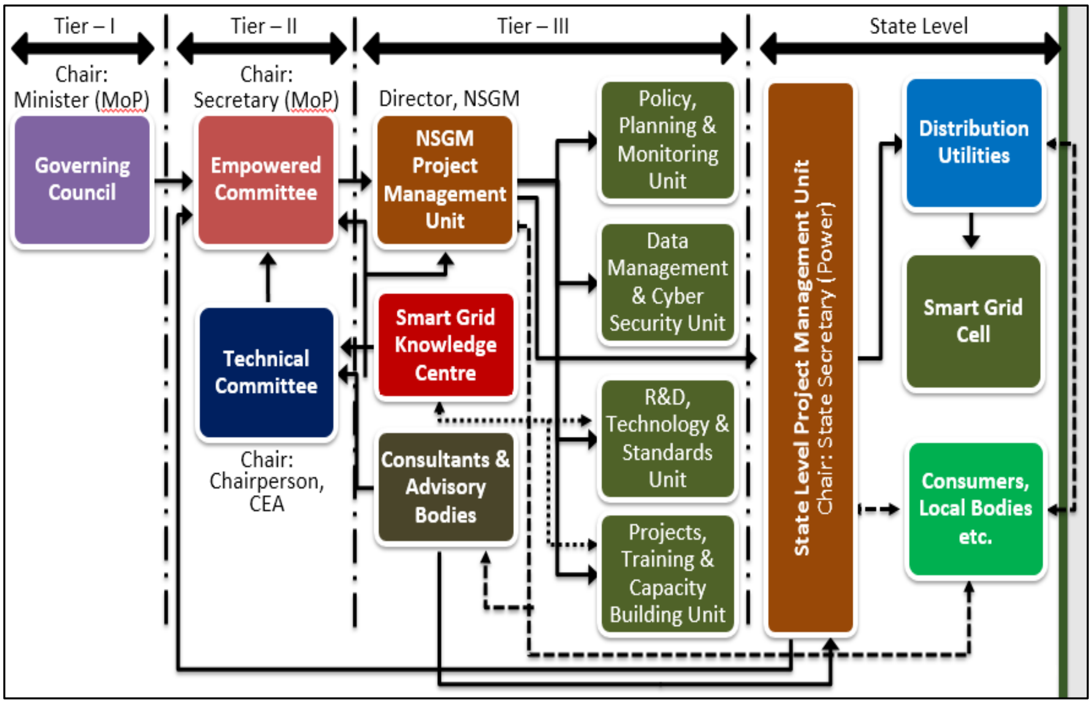

Fig. 7 GoI organizational structure for NSGM.

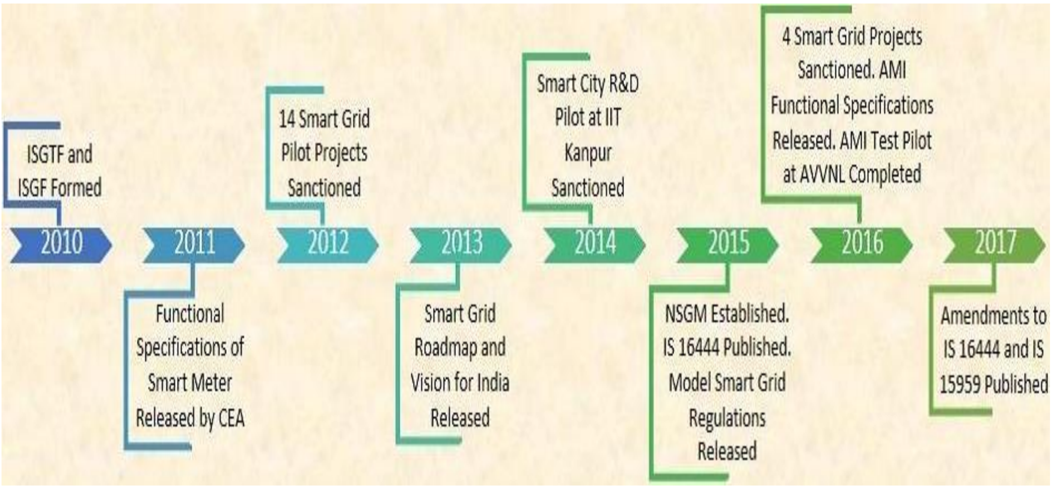

Fig. 8 Formation of NSGM and activities.

3.3. Pilot Projects under NSGM

GoI supported a total of 14 smart grid projects to test various technologies with 50% funding support from MoP. The list of supported pilot projects are shown on Table 2 (Li Chao, 2011). However, the budget details of most of the pilot projects were not available due to many socio-economic and political challenges and issues in the implementation.

Table 2 Complete SG pilot projects sanctioned by GoI.

S.No.	Project Description	Project Area	Cost in Crores	Consumers
1	11 Smart Grid Pilots (WIP)	Across India	333.2	1,84,801
2	IIT Kanpur Smart City Pilot (WIP)	IIT Kanpur	12.5	IIT Campus
3	Smart Grid Projects under NSGM (WIP)	Amravati, Congress Nagar (Nagpur) & Chandigarh	257.8	3,03,341
4	Smart Grid Project by BESCOM (WIP)	Indira Nagar (Bangalore)	N.A.	26,911
5	SG project at TPDDL (WIP)	Delhi	N.A.	5,000 endpoints in phase 1
6	Smart Grid Project by CESC (WIP)	Kolkata	N.A.	1st ph- 1,87,000 Total-7,50,000
7	Smart Prepaid Metering on BOOT Model	Across Odisha	N.A.	1stPhase-4,237 Total- 18,046
8	Smart Grid Demonstration Project by POWERGRID	Puducherry	N.A.	1,658 Meters
9	Smart Grid Pilot - PoC by UGVCL	Naroda (Ahmedabad)	N.A.	1,500 Meters
10	Meerut AMI project (WIP)	Meerut (UP)	N.A.	13,751 Meters
11	Gaya (Bihar) WIP	Gaya (Bihar)	N.A.	10000 Meters
12	Muzaffarpur AMI project	Muzaffarpur (Bihar)	N.A.	5,000 Meters
13	Tata Power AMI project	Mumbai	N.A.	10,170 Meters

4. Challenges to implement SG

The main challenges in the implementation SG projects in India were categorized into three types as follows: (Kappagantu & Daniel, 2018)

1. Technical challenges
2. Socio – economic challenges
3. Other policy implementation challenges

4.1 Technical challenges

1. Infrastructure inadequacy: The infrastructure available for the existing conventional grid is not sufficient to upgrade it to SG. Lack of infrastructure leads to further challenges like design, operation and maintenance of SG to provide clean and reliable power to the utilities.
2. Cyber security: Cyber security is one of the key challenges in the implementation of SG as the electric network is integrated with information network. Availability, Integrity and confidentiality are three key factors for cyber security of SG. SG is multi layered network and each layer needs its own security concerns.
3. Storage of power: SGs are accommodated with large number of interconnections from renewable sources like wind, solar, bio mass and small hydro, it is necessary to plan about the storage technologies

while implementing SG projects. Battery is one of the common storage technology for most of renewable energy sources and the life time of the battery is limited upto 4 to 5 years. The cost of the batteries and the raw material inadequacy for design are the major concerns for the storage technologies.
4. Data Management: In SG AMI is one of the key technology to manage data transfer and management. These smart meters enable the data collection for every 15 minutes instead of monthly data which leads to a bigger database and its security. This high volume of data collection can cause low operational speed of SG.
5. Communication networks: Communication networks are the another key challenge in the deployment of SG projects. Different types of communication networks like GSM, GPRS, ZigBee, PLCC and broadband are using in the implementation of SG. Each technology has its own limitation in bandwidth, operating distance, data loss and underground installations. Optical Fiber technology and RF technology can solve these problems but these technologies are limited due to their cost effectiveness for SG.
6. System stability: SGs are developed toward the distributed generation which leads to bidirectional power flow. The synchronization of these distributed sources to the grid leads to stability issues in terms of voltage and frequency.
7. Energy management and electric vehicles: Electric vehicles is one of the innovative concept emerging in the implementation of SG projects India. The main concept behind the usage of electric vehicles is to store the energy in off peak hours and use the electric vehicles in peak periods. This concept has the challenge of storage infrastructure.

4.2 Socio economic challenges

In addition to the technical challenges, socio economic challenges are also play a vital role in the implementation of SGs. The important socio economic challenges are listed below

1. High capital investment
2. System operation
3. Lack of skilled manpower
4. Lack of understanding and awareness
5. Stakeholders involvement
6. Privacy and health issues due to RF signals

Regulation and policies, power theft, coordination between different entities of SG are the other challenges in the implementation of SG pilot projects in India.

5. Strategies and road map for future SG projects

GoI planned a detailed roadmap with different strategies to address all the above mentioned challenges in the implementation of SG projects effectively in India (Li Chao, 2011).

The different strategies for the implementation of SGs in India are

1. Deployment of SG in smart cities
2. Efficient use of existing sources through Smart Grid – DSM/DR/PLM/PQM
3. Three full scale projects SG Projects worth Rs. 258 Crores sanctioned under NSGM
4. Industry can join hands under ESCO model: High T&D Loss
5. 35 million Smart Meters installation envisaged by December 2019 - UDAY mandate
6. Impending proliferation of Electric Vehicles- creation of charging infrastructure
7. 40000 MW of roof top PV by 2022 – Smart Grid the key to efficient integration & facilitating ‘prosumers’

This is the complete road map designed by GoI under NSGM to implement different strategies for SG projects in India.

6. Conclusion

India as a developing country and with an increasing population will have greater increases in energy demand in the future, particularly in achieving the aim of the "POWER FOR ALL" project initiated by the GOI. Adoption of SG can support achieving the targets of this project. The major challenges for SG implementation are renewable sources integration, data management, stability and cyber security can be solved by multiple approaches by researchers, together with the SG entities, by trial and implementation programs through several pilot projects. The funding support from the government and private bodies is a big help in financing the high investment costs of SG projects. The socio-economic challenges can be solved by the joint efforts from all the SG participating entities. Through different training and awareness programs, manpower can be trained and awareness and understanding of consumers can be improved. The clear road map and the strategies designed by GOI, including regulations for SG and the different pilot projects implemented can transform the existing conventional Indian electric grid to a promising smart grid in the future, to serve nation with reliable, quality and secured power in a smarter way.

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