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Smart grid and Indian experience: A review

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ABSTRACT

The present lifestyle of the mankind thrives on the consumption of energy thereby making it an inevitable necessity. The increasing population has led to an ever-growing energy demand. Majority of this demand is met through conventional sources which are continually depleting and raising serious environmental concerns. To further prolong the issue, the present power structure of developing countries like is ageing, inefficient and unsustainable. The present electricity grid is unreliable, prone to brownouts and blackouts, has high transmission losses, poor power quality, supplying inadequate electricity, discouraging to integration of distributed energy sources. Mitigation of these issues require the complete overhauling of power delivery structure. Smart Grid, i.e., the modernization of the electric grid is an evolving blend of various technologies intended at bringing a drastic change in the electrical power grid. The constituents of smart grid and its need in the Indian context has been discussed. This work inclusively covers the various enabler schemes and governing bodies formed by the Indian Government for expediting the smart grid deployment. Further, a comprehensive and updated review of Indian smart grid's initiatives and experiences is presented. And based on these experiences, potential barriers have been identified and their solutions are discussed.

1. Introduction

The pervasive consumption of energy in all the wakes of life has made it an inevitable necessity. Modern life and industry thrive on round the clock electricity supply. The electricity network, also known as electric grid, has been delivering electric power to consumers from the suppliers since its inception. Comprising of power stations, transmission lines, storage facilities, distribution lines, power switches, transformers, measuring equipments and loads, the electric grid is presently running down to meet the power quality and quantity demands. The Indian population has reached 1.339 billion (India Population, 2017), which point towards a continuous and ever-increasing consumption of electricity. The existing infrastructure is inefficient, aging and vulnerable to various faults, which is ultimately unable to meet the pressing demand of the required energy. In various parts of the country, the electricity demand is yet to be fulfilled. According to Central Electricity Authority (CEA), the peak deficit and energy shortage of the country were 1000 MW (0.6%) and 600 MU (0.5%) respectively in the month of May 2019 (Central Electricity Authority, 2017). To attain the requirement of this unaddressed energy demand, effective planning is necessary for both in the discipline, i.e., increase in the efficiency of the existing resources as well as up gradation of the infrastructure of the utility grid. Also, the emissions from the conventional sources of energy are degrading the environment, which has necessitated the finding of alternative clean sources for electricity generation. The existing grid also doesn't facilitate easy integration of distributed and renewable energy sources. The renewable energy sector is witnessing a remarkable growth in recent years. The installed capacity of renewable energy sources in India is 78,360 MW as of April 30th, 2019 which is 22% of total installed capacity of energy generation (G. of India, 2011). Such growth in renewable energy generation has to be seamlessly integrated into the grid and meet through efficient energy utilization.

With power cuts rampant in the country and recent experiences with blackouts, increasing the grid reliability is essential, which makes the modernization of the existing electricity grid inevitable. At the present moment, conservation of energy and reduction of emission, sustainable advancement, clean energy, security, loss minimization, optimal utilization of assets have become the prime areas of consideration. Being an emergent technology in the field of grid modernization, smart grid offers various benefits of power quality, reliability, increased efficiency and economical pricing, which can be a possible solution for developing countries like India's concern over the scarcity of energy.

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For supporting the worldwide transition to a smarter grid, sharing of information and lessons learnt from pilot projects implementation is important. With smart grid being a costly and non-matured technological venture, the proper feasibility study before deployment is necessary especially in the cases of developing countries. Surveys about smart grid implementation in different countries can be accessed in the literature (Di Santo et al., 2015; Colak et al., 2014, 2015; Haidar et al., 2015; Yuan et al., 2014). The lack of proper and detailed information and experiences from Indian smart grid endeavors compelled the authors to undertake this work (Arya et al., 2016; Murthy Balijepalli et al., 2009; Kappagantu et al., 2016; Bala et al., 2012; Rihan et al., 2011; Asaad et al., 2018). only provide case study of selected smart grid projects across India (Kovendan and Sridharan, 2017). only lists key government's enabler policies and technologies of smart grid (Chandel and Tripta, 2016). only lists the 14 smart grid pilot projects under Ministry of Power, Government of India and misses various other smart grid projects functioning in the country (Thakur and Chakraborty, 2015). provides thorough details on smart grid architecture and technologies along with perceived barriers in deployment on global scale but fails to capture challenges specific for India and their potential solutions. Also, the project coverage is only limited to 14 pilot projects under Ministry of Power, Government of India (Chandel et al., 2015). provides a comprehensive review of various smart grid projects undergoing in India up to year 2015 but aside from missing few major projects, fails to address the key challenges in their implementation and possible solutions for smooth countrywide deployment of smart grid.

Thus, this work is aimed to present a complete review of smart grid initiatives and experiences by India. It describes updated and inclusive details of numerous smart grid projects completed and under fruition in India. Further, these projects are confronted with many roadblocks which are also comprehensively listed and viable resolutions are provided aimed for incorporation into policy framework to expedite the smart grid implementation process in India and likeable scenarios around the world.

The paper is organized as follows. Section II gives the background of smart grid concept-necessity, advantages, functionalities etc. Section III sheds light on existing energy scenario of India and explains the need of smart grid in India. Section IV lists the various plans/schemes of Govt. of India to modernize the existing utility grid along with details and functionalities of governing bodies involved in smart grid implementation. Section V provides a complete and latest update on smart grid pilot projects directly operated by the Ministry of Power, Govt. of India. Section VI enumerate various other smart grid projects operative in India. Section VII presents key drawbacks and roadblocks in smart grid deployment and further suggest potential solutions to mitigate these challenges.

2. Smart grid concept

Since its inception, the electricity flow has been primarily in one direction i.e., generation is done at central power stations and sent to distributed consumers. The power plants are made to generate necessary electricity as per the total load requirements. All the sectors of the utility grid i.e., generation, transmission, distribution, and trading have been under the total control of a central organization. With the passage of time, existing technologies are being modified and innovations are integrated. The greatest artificial engineering marvel of 20th century i.e., the electric grid has also undergone and still going through overhauling making it more resilient, stable and intelligent, hence the term "smart grid". It is the intelligent integration of distribution, transmission, generation for the efficient delivery of secure, sustainable and economic electricity. It enables various smart and automatic applications such as advanced metering infrastructure (Chou and Novi Yutami, 2014; Siano, 2014), demand response (Xue et al., 2014; Song et al., 2013), smart distribution management (Fotouhi Ghazvini et al., 2012; Yekini Suberu et al., 2014), intelligent energy storage (Fares and Webber, 2015; Ahmad et al., 2017a), advanced electricity marketing (Bae et al., 2014; Wang et al., 2012; Mwasilu et al., 2014), emission trading (Wang et al., 2012) and integration of electric vehicles (Ahmad et al., 2017b; Ahmad and Alam, 2017). Using automated control, smart sensing and metering equipments, energy management methods, intelligent converters, and state-of-the-art communication technology, smart grid improves the efficiency and reliability based on the optimization of demand, intelligent protection, and energy and network accessibility.

The advancement in the technology has made the integration of distributed and intermittent renewable energy sources possible making the flow of electricity multidirectional i.e., distributed generation along with centralized one. The participation of consumers is also active in nature. With the accessibility to the incentives, disincentives, choices and knowledge, consumers' electricity purchasing pattern and behavior is changed. Based on the consumers' choices, incorporation of latest technologies is necessary. The government centric energy sector is also viewing massive non-central involvement thus increasing competitiveness, accountability and responsibility. The structure of a smart grid is shown in Fig. 1.

The key attributes of Smart grid can be classified as:

- **Generation**
  - o Renewables & Microgrid (MG)-

With the help of the smart grid, off-grid generation sources can be incorporated into the national grid in a rational and balanced way. For example, energy management centre can dispatch off-grid generation and use it at only peak times. The cost of off-grid generation will be compensated by suitable feed-in tariffs, and customers will be protected from high pricing by merging the cost of an off-grid generation with the average weighted price of electricity used in the tariff (Ahmad et al., 2017b, Ahmad and Alam, 2017).

- **Transmission & Distribution**
  - o Integration of Renewable Energy sources/Distributed Energy Resources (DER)-Renewable energy sources (RES) which are intermittent in nature are easily integrated into smart grid and availability of real-time information enable system operators to select generation from clean energy sources, thus substituting renewable energy whenever possible.
  - o Advanced Metering Infrastructure (AMI)- AMI is an architecture for bilateral, automated communication between a smart meter and utility. The aim of AMI is to provide real time power consumption data to the utility companies and enable the consumers to make informed choices based on their energy usage pattern.
  - o Outage Management System (OMS)- OMS recognize and resolve outages in an efficient manner. It generates and records relevant historical data. It also enables the utility to alert the consumer of the outage situation and restoration status (instead of consumer notifying the utility initially).
  - o Peak Load Management (PLM)- Load management techniques like Pricing based schemes, Direct Load Control (DLC), curtailable services, demand bidding, etc. are used to help the consumers to lower their payments and utility to minimize the need of peaking plants (Jeff and Dilip, 2007).
  - o Power Quality Management (PQM)- It deals with the control of the quality of the electric power supply. Concerning issues are harmonics and distortion, transients, power factor, voltage sags and dips, current and voltage instability. It helps in extending equipment's life, avoids overloading of the system that can damage equipment and reduces the risk of power failure and saves on repair costs.
  - o Electric Vehicles- V2G- Electric Vehicles (EVs) integrated into the smart grid can act as dynamic loads by consuming power from the grid (during charging) or dynamic energy storage system by

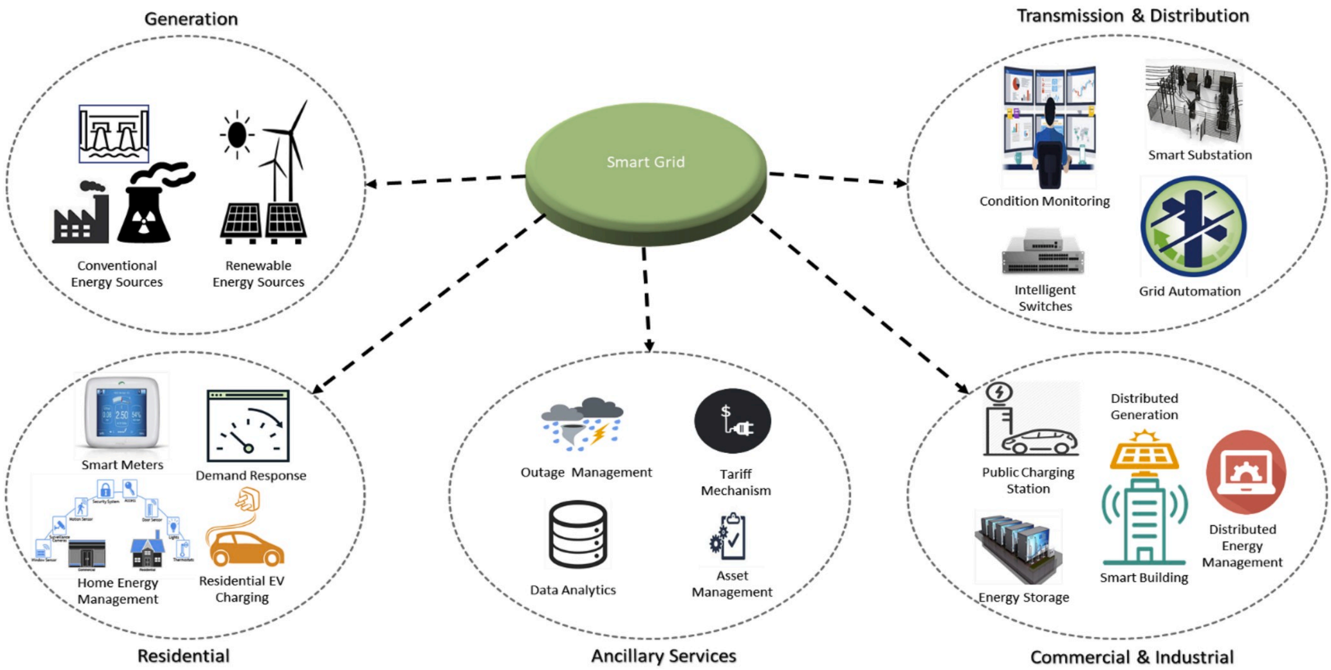

Fig. 1. Structure of a smart grid.

supplying power to the electric grid when not in use (Vehicle to Grid-V2G) (Amrr et al., 2018; Asaad et al., 2017a, 2017b).

- o Wide Area Measurement Systems (WAMS)- It helps in avoidance of outages as the result of an accurate early warning system, congestion mitigation through better system margin management and better "state estimation" for the location marginal pricing that will be increasingly required to enable transmission grids that optimize competitive markets.
- o Energy Storage- Due to intermittent nature of RES, Energy Storage System (ESS) are needed to store the surplus electricity. To balance out the fluctuations in voltage and frequency in case of load variation in the grid, smart ESS can take in or distribute power within milliseconds.
- o Demand Response- Smart grid facilitates an all-time demand response where the consumers can see incentives for regulating their energy usage instead of traditional event-based demand response where the utility request shedding of the load.
- o Distribution SCADA/Distribution Management- Distribution Management System is an accumulation of applications designed to monitor & control the entire distribution network efficiently and reliably by minimizing outages frequency and duration, upholding standard frequency and voltage levels. It facilitates the monitoring and control of the electric distribution system.

- **Ancillary Services**
  - o Data collection and analysis- The aim of data analytics is to generate actionable insight to drive efficiencies, improve reliability and enhance the quality of service. The majority of analytics are-
    - Analysis based on consumer profitability
    - Determination and awareness of transmission grid system based on the information gained from Phasor Measurement Unit (PMU) reporting the health on an ongoing basis
    - Distribution networks analysis regarding grid optimization (e.g., measurement of voltage) (Data Analytics and Smart, 2012)
  - o Tariff Mechanism- It includes interruptible and dynamic rates, Real Time Pricing (RTP), Critical Peak Pricing (CPP), Time of Use (TOU) pricing to flatten the overall demand over time and thereby reduce peak load (Lancaster, 1989).
  - o Asset Management- While creating new and complex asset classes, smart grid provides options for asset management by realigning asset groups uniting similar characteristics, realigning depreciation rate, creating a centralized asset health centre, making a holistic asset data strategy, developing a proactive asset strategy process, etc. (Sidney)

Table 1 shows the comparison of the characteristics of a smart grid with an existing electric grid.

3. Energy scenario and need for smart grid in India

The presence of vast untapped renewable energy potential in India necessitates the intervention from the government to solve the ongoing deficit in the demand and supply of the electricity. Due to intermittent nature, the integration of renewable energy into electric grid is a difficult and costly affair. This section sheds light on Indian energy scenario with a focus on renewables and highlights the issues which demands the modernization of present grid into smart grid.

The total installed capacity for electricity generation in the country is 356,817 MW as on May 31st, 2019, out of which 46.3% generation is credited to private sector, 24.3% to central sector and 29.4% to state sector. Most of the electricity generation is thermal based accounting for 226,279 MW i.e., 63.4%. Coal based thermal power plant is the most dominant in thermal based electricity generation by generating 194,444 MW which is 54.5% of the total installed capacity in India. Another rising sector is the Renewable Energy sector whose installed capacity stands at 78,360 MW as of April 30th, 2019 which is equivalent to 22% of the total installed capacity. RES includes Small Hydro Project, Biomass Gasifier, Biomass Power, Urban & Industrial Waste Power, Solar and Wind Energy. Combining with the hydro based installed capacity which is 45,399 MW or 12.7% of the total installed capacity, the total installed generation from the renewable sources is 34.7% of the total electricity generation in India (G. of India, 2011). With energy demand of India expected to reach 400,000 MW, a major share of demand is expected to fulfill by renewable energy sources. It is estimated around 215,000 MW of electricity will be generated by renewable energy sources by 2030 with hydel plants generating 50,000 MW, wind farms producing 65,000 MW and 60,000 MW tapped from solar energy

Table 1
Characteristic wise comparison of smart grid with existing grid.

Characteristics	Existing grid	Smart grid
Nature of components (e.g., relay, circuit breakers)	Electromechanical	Digital
Electricity generation	Centralized system	Integration of Distributed Energy Resources into Centralized generation
Tolerance toward faults	Fault intolerant	Fault tolerant
Restoration process	Manual	Automatic (self-healing)
Outages	Prone to failures and blackouts	Adaptive and islanding facility
Tariff and Pricing	Fixed	Dynamic
Energy storing	Demand based production	Energy storage system
Transparency	Less	High
Consumer choices	Few	Increased choices
Communication between utility and consumer	Unilateral (from utility to consumer)	Bilateral
Security	Limited	Substantial
Emission of GHGs	High amount of emissions	Reduced emissions
Sensing and Monitoring	Few sensors present and manual monitoring	Large no of sensors and self-monitoring
Structure	Hierarchical and rigid	Networked and adaptive/scalable
Transmission efficiency	Less efficient	Highly efficient
Enabling of new services and market	Limited wholesale market and services	Mature, well-integrated market and support for new services (V2G, DSM etc.)
Demand response	No consumer participation and load following demand response	Adequate consumer participation and use of load shaping strategy of demand response
Power Quality	Slow response to power quality issues as focus is on outages	Power quality is a priority with rapid resolution of issues
Response towards disturbance	Responds after fault to prevent further damage to assets	Automatically detect faults and responds to prevent/minimize the impact
Asset management	Little integration of operational data with asset management	Greater acquisition and integration of operational data with asset management

(Lancaster, 1989). For realizing this potential of renewable energy, the present electricity grid needs to be restructured to seamlessly integrate generation from these sources into main utility grid.

Another driving reason for India to implement smart grid is the ageing and inefficient transmission network. Despite being having the third largest transmission network, Aggregate Technical and Commercial (AT&C) losses in the transmission stands currently at 20.42% (AT and C LOSS, 2017). Apart from this, issues like electricity frauds where tampering is done with the meter, electricity theft in which a line is rigged from the power to the location of its usage, wrong readings taken from the meter, by passing the meter and so on leads to the loss of almost one-third of the electricity generated. These issues cause loss in government revenue which results in inability of utility to preserve the grid or make new addition to increase the generation capacity. Eventually, there is an increase in taxation which is borne by legitimate consumers. Other effects are increased power failures, load shedding during peak hours, and equipments (e.g., transformers) failure. Smart meter, which is an integral part of the smart grid, would provide a check on these irregular practices and thefts.

The issue of power quality is a powerful reason for India to adopt smart grid. There are three fundamental issues affecting the quality of Indian power supply-unavailability of power in rural areas, frequent outages and voltage fluctuations. Harnessing the untapped renewable energy through microgrids can avail power in un-electrified rural areas and remote places where providing centralized main grid electricity is not economically feasible. The generated electricity can be used for irrigation, lighting homes, and small businesses while avoiding power outages. The high initial cost of the installation of microgrid is the major drawback in realizing their full potential. This leads to increase in price of electricity compared to centrally generated electricity. The Government of India has formulated many policies and subsidies to encourage the installation of microgrid. These are discussed in next section. The inherent features of smart grid e.g., real time situational awareness, fault location and isolation, computational ability, integration of sensors and ICT devices, and voltage control through reactive power control improves the overall voltage profile and enhances the reliability of microgrid. Addition and proper management of energy storage devices helps in avoiding the stochastic nature of electricity generation from renewable energy sources.

Security of the grid and reliability of electric supply is also a necessity. Recent natural calamities like floods, cyclones have created a huge affliction to the power infrastructure, e.g., the Vardha cyclone damaged around 32,000 electric poles and 800 transformers in Tamilnadu state (Srikanth, 2016). The electric grid also faces threats due to operational & technical failure, e.g., blackout in 2012 due to surplus power drawing in the northern region of India left millions in the dark. With our growing dependence on the digital and automated services, these events underscore the threat posed by power interruptions to businesses as well as public health and safety. Hence, upgrading grid system to be stable & sustainable can help in avoiding these interruptions.

For a large democracy like India, smart grid is a driving factor which augments the sustainability drive of India and positively impacts the policy making. It is an integral part of core strategies tackling climate change (green energy source integration, emission reduction, energy efficiency increment). Along with it, the Indian energy sector also benefits by technological innovations, operations cost optimization, competitiveness and variety buildup. The planned implementation of smart grid improves country's economics e.g., business and job creation, reliable electric supply, loss reduction, power quality enhancement, consumption of locally produced energy. The consumer participation in a sustainable technology like smart grid increases the awareness for the sustainability issues in general and encourages involvement in other sustainable schemes. For a large democracy like India, mass awareness and action from the population will ease the efforts of policymakers considerably. Also, it paves way for effortless adoption of new technologies imperative for promoting sustainability e.g., electric vehicles (Mohammad Asaad et al., 2017). Human intervention, risk of personnel lives etc. are the few factors associated with the developing economies due to which consumers see tremendous benefits from smartening of power sector. However, large developing economies also have fiscal issues which are convoluted by investments in the state-of-the-art technological ventures. Therefore, feasibility analysis through pilot projects, surveys, proper planning and roadmap are pre-requisites for large developing economies like India.

4. Indian smart grid initiative

Taking in account the benefits and the necessity of the smart grid, The Government of India (GoI) is envisaging to completely overhaul the utility grid. The smart grid market in India is expected to reach $7.4 billion (' 50,000 Cr) by 2020. The biggest driver for the smart grid is the Smart City Mission discussed in next paragraph. Apart from the Smart City Mission, Govt. of India has been trying to improve the electric grid infrastructure through various schemes, which are advantageous for transformation of present grid into smart grid. This section comprehensively lists those schemes and further gives a brief overview of the governing bodies involved in the deployment of smart grid in India.

4.1. Smart City Mission

The Government of India launched a mission in June, 2015 focusing on rejuvenation, retrofitting and creation of satellite towns around the existing cities to develop them as smart, technological and sustainable cities. The Union Ministry of Urban Development is working in collaboration with state governments of respective cities to achieve this mission. The two schemes for development under this mission are:

- Smart Cities Mission for developing 100 Smart Cities
- Atal Mission for Rejuvenation and Urban Transformation (AMRUT) for rejuvenation of 500 towns across India

Total budget allocation by the Indian Cabinet for urban development mission is ₹980 billion which is further distributed as ₹480 billion for the Smart Cities mission and ₹500 billion for the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) (Cabinet nod To Rs 1 lakh, 2015).

Fig. 2 shows the region wise distribution of 100 smart cities chosen under this mission.

20 cities were selected to be the beneficiaries of the first-year financing starting from 2016 onwards. Further details and name of all cities can be accessed at (Smart Cities Mission and Gov).

The Smart Grid can be an anchor infrastructure for the development of the Smart City. Some of the automation and IT systems of smart grids can be outspread to other areas such as water distribution, gas distribution, traffic and security etc. thereby reducing the overall expenditure. Basic communication and automation solutions are implemented by all state-owned electricity distribution companies (DISCOMs) under the ongoing R-APDRP (Restructured-Accelerated Power Development & Reforms Program) scheme of the Ministry of Power. Overall cost of building smart cities can be considerably reduced by leveraging some of the resources created under RAPDRP which already covers 1,405 towns. The assets and smart infrastructure created under various schemes of Govt. of India are listed as follows:

1. Geographic Information System (GIS) Mapping of the Cities
2. Billing and Customer Relationship Management Systems
3. SCADA/DMS System
4. Common Command and Control Centre
5. Outage Management Systems and Mobile Workforce Management (MWFM)
6. IT Network, Data Centre and Disaster Recovery Centre (Pillai and Sawant, 2016).

Apart from smart cities project, following programs of GoI have necessitated the existence of the Smart Grid as the enabling infrastructure:

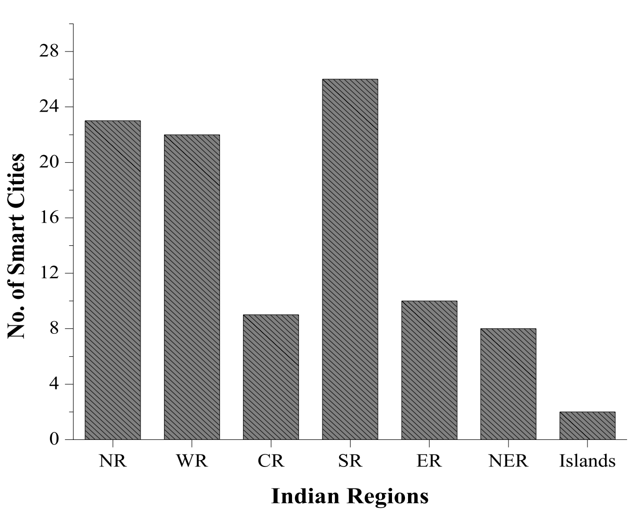

Fig. 2. Region-wise distribution of Smart Cities in India.

- Round the clock electricity supply
- 175 GW of renewable energy by 2022 with 100 GW from solar
- National Electric Mobility Mission with a target of complete electrification of transport system by 2030
- Adoption of 6–7 million Electric Vehicles by 2020 under FAME India Mission
- 35 million smart meters within the next four years
- 40% of electricity generation from renewable sources by 2030

Following schemes of GoI are in implementation stage aiming to modernize the electric grid:

A **R-APDRP (Restructured Accelerated Power Development & Reforms Program)**

It was launched in 2008 with the aim to reduce AT&C losses and to enable the utilities with Information and Communication Technology (ICT) with approved cost of $7.5 billion (’ 51,577 Cr). It is divided into two parts- A & B.

Part A involves preparation of Base-line data for the project area involving consumer indexing, Geographical Information System (GIS) mapping, metering of distribution transformers and feeders, and automatic data logging. 1,388 towns out of 1,405 sanctioned have already completed work in Part A.

Part B entails renovation, modernization, and strengthening of the distribution system. 1,195 towns out of 1,227 have already strengthened their urban distribution system (URJA - URBAN JYOTI ABHIYAAN, 2017). This program is now merged with IPDS.

B **IPDS (Integrated Power Development Scheme)**

Launched in 2015, this scheme is focused on the strengthening of sub-transmission and distribution network, improvement of the metering system and integration of ICT in the distribution segment. Total outlaid cost to implement this scheme is estimated at $11.1 billion (’ 76,623 Cr) with $6.9 billion (’ 48,081 Cr) support from GoI. $3.9 billion (’ 26,639 Cr) has been sanctioned till date (Project Monitoring, 2017).

C **UDAY (Ujjwal Discoms Assurance Yojana)**

The GoI announced the UDAY program for financial restructuring and performance enhancement of electricity distribution companies (DISCOMs) in 2015. This scheme stresses on increasing operational efficiency and reduction in transmission and commercial losses of each state, to 15 percent from the current level by 2018–19. It aims to lower the debts of financially stressed discoms. The financial losses of UDAY participating states have been reduced from $7.4 billion (’ 51,589 Cr) in FY 2016 to $5.05 billion (’ 34,826 Cr) in FY 2017. It also seeks to improve ‘last-mile’ transmission and distribution, eliminating the disparity between average revenue collection and the average cost of purchasing by 2018–19. The UDAY scheme enables the deployment of smart meters (as per IS 15959 Part-2 and IS 16444) through DISCOMs for all energy users with consumption above 200 kWh per month ((UjwalAssura, 2015).

D **DDUGJY (Deen Dayal Upadhyaya Gram Jyoti Yojana)**

This scheme was launched in 2015 by GoI for rural electrification with the budget of $10.9 billion (’ 75600 Cr). The existing Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) scheme for village electrification and providing electricity distribution infrastructure in the rural areas has been subsumed in the DDUGJY scheme. Under this scheme, GoI has sanctioned 921 projects to electrify 597,464 un-electrified villages and provide free electricity connections to 39.7 million BPL rural households. India achieved 100% electrification on April 28th’ 2018, however remote villages only see few hours of electricity per day

(Deendayal Upadhyaya Gram Jyoti Yojana, 2017).

E **Saubhagya Yojna**

This scheme was launched in September 2017 with an aim to provide electricity to over four crore families in rural and urban areas by December 2018. With budget of $2.4 billion (' 16,320 Cr), this scheme promises to provide a free electricity connection to all willing Below Poverty Line households (Tata discom selectsM f, 2013).

4.2. Renewable energy schemes

Along with the various strategies, regulations, and acts, Govt. of India has been encouraging the usage of wide range programs, including saddling renewable power, RESs based electrical energy in provincial regions for lighting, cooking and intention control, utilization of Renewable Energy in urban areas, mechanical and business applications and improvement of interchange powers and applications including exploration, planning, and advancement of new and renewable green energy technical approaches. A brief detailed of schemes related to promotion of renewable energy in India is shown in Table 2.

4.3. Energy storage projects

With Energy Storage being an integral part of the smart grid, Govt. of India has announced the launch of three projects amounting to cumulative capacity of 55 MWh. These energy storage systems are to be integrated with existing solar projects in Andaman & Nicobar Islands. These projects are:

A **Chidiyatapu-**

This project entails grid integration with 8 MW solar PV project and 3 kV grid, of 3.2 MW, 3.2 MWh (at 33 kV output) Battery Storage System (BSS).

B **Manglutan-**

This project integrates BSS with 17 MW Solar PV Plant and 33 kV grid, of 6 MW, 24 MWh (at 33 KV output).

C **Port Blair-**

This project involves installation of 2 × 10 MW (AC) Grid interactive Solar PV Power Project integrated with 28 MWh BSS at Attam Pahad and at Dolly Gunj, Port Blair (at 33 kV output) (INDIA SMART GRID, 2012).

4.4. Governing bodies

To accentuate the deployment of smart grid and assessing the feasibility of pilot projects, Govt. of India has constituted many governing bodies in this regard.

Details of the concerned bodies are as follows:

A **NSGM (National Smart Grid Mission)**

NSGM was formulated by Govt. of India in August 2013 for monitoring, planning and implementation of programs and policies related to Smart Grid. The aim of NSGM is to address key issues related to deployment of Smart Grid on a nation-wide scale and make the present Power infrastructure cost efficient, reliable and responsive. Fig. 3 shows the framework of the National Smart Grid Mission and the different bodies involved in it (Energy Efficiency Service, 2017).

B **ISGF (India Smart Grid Forum)**

Table 2
Schemes of goi to promote renewable energy (Ahmad and Alam, 2018).

Mission/Scheme	Active From	Type & Size of component	Significance
National Wind Mission	2015	Wind	Goal of 60,000 MW generation by wind energy by 2022 against the Rs 10,00,000 crore investment
Jawaharlal Nehru National Solar Mission	2010	Solar, 40 GW rooftop, 60 GW small and large solar PV plants	Phase 1: 2010–13, Phase 2: 2013–17, Phase 3: 2017-22 It is predicted to abate over 170 million tons of CO_2
National Mission for Enhanced Energy Efficiency (NMEEE)	2010	23 million tons fuel saving every year and GHG emissions reduced by 98.55 million tons every year.	NMEEE goals is to fortify the market for energy efficiency by forming conducive regulatory and strategic organization and has visualized fostering state-of-the-art and sustainable commercial framework to the energy efficiency sector
Solar cities development program	2011	Solar	Overall 60 cities/towns are planned to be reinforced as Solar Cities during the 11th Plan period
MNRE-USAID PACE-D TA program	2009	Solar PV rooftop	Constructing an enabling environment at the national as well as at state level
National Biomass Cook-stoves Initiative (NBCI)	2009	Biomass	It lay emphasis on improvement of specialized potential inside the nation by innovative techniques, accreditation and observing administrations and fortifying R&D programs in key specialized research centre
Solar Power Generation Based Incentive	2008	Solar	In order to promote and develop RE based infrastructure, it provides incentives in term of Solar feed in tariff rate as Rs 12 for solar PV system as Rs 10 for solar thermal based power plants
Generation based incentives for wind power	2008	Wind	It was designed to encourage investment in new and large wind based IPPs, to achieve target of 10500 MW of wind energy installed capacity at the end 2012
India-Brazil-South Africa Declaration on Clean Energy	2007	Multiple RE Sources	Secure, reliable, sustainable green energy production to meet global energy demand
Village Energy Security Test Projects (VESP)	2004	Biomass energy	Toward the end of January 2011, a sum of 79 VESP tasks were authorized in 9 states and 65 of these ventures were completely appointed, now more than half of them not functioning
Central Financial Assistance (CFA) for Biogas Plants	2004	Biogas	To make Biogas Development and Training Centers

(continued on next page)

Table 2 (*continued*)

Mission/Scheme	Active From	Type & Size of component	Significance
			(BDTCs) accessible, for correspondence and attention purposes, and to bolster the repair of old and non-operational plants
Government Assistance for Small Hydropower Stations (SHP)	2003	SHP	Extended economic and monetary incentives for the development SHP
Government Assistance for Wind Power Development	2002	Wind	To promote the development of wind energy it provides the provision of preferential loans for wind turbine stockholder

To accelerate the development of smart grid technologies in India, Ministry of Power, Govt. of India devised the Indian Smart Grid Forum (ISGF) in 2010. Purpose of ISGF is to work as advisor to the government on policies and programs for promotion of Smart Grids in India. Also, ISGF works with various agencies for development of standards and helps utilities, regulators and the Industry in capacity building, training and technology selection (India Smart Grid Forum, 2017).

C **ISGTF (India Smart Grid Task Force)**

Govt. of India formed ISGTF as an inter-ministerial group to serve as a government focal point on activities related to smart grid deployment in India. With 5 working groups, its function is to increase awareness, ensure coordination among different utilities, regulators and review and validate recommendations from ISGF. It also coordinates and integrates inter-ministerial activities pertaining to smart grid (National AssessmentAccreditation Council, 2013).

D **EESL (Energy Efficiency Services Limited)**

A joint venture of Public Sector Undertaking (PSU) under the Ministry of Power, GoI, EESL launched in 2015 facilitates implementation of energy efficiency projects. Under EESL, 350 million LED bulbs, 140k solar street lighting systems and, 9.4 million street lights retrofitted with LED lights (Smart Grid Feasibility Study and India).

5. Govt. of India's smart grid pilot projects

With smart grid being a costly and non-mature venture, the Ministry of Power which is a division of Govt. of India has approved 14 pilot projects in 2013. The aim of these pilot projects is to assess the feasibility of smart grid and ascertain various challenges in implementing smart grid. Out of these 14 projects, two projects (Jaipur, Baramati) were canceled, and tender of one project (Gujarat) was floated again, which has commenced recently. Further, Govt. of India introduced one more project in Kanpur and one resource centre in Manesar. 4 more projects were introduced under NSGM. Fig. 4 shows the location of these pilot projects.

The smart grid pilot projects are being implemented in different states due to broad diversity in generation, transmission and distribution of electricity in Indian states. Also, there is diversity in social and economic needs of the people in different states. These pilot projects would give useful insights into the feasibility and improvements required in the

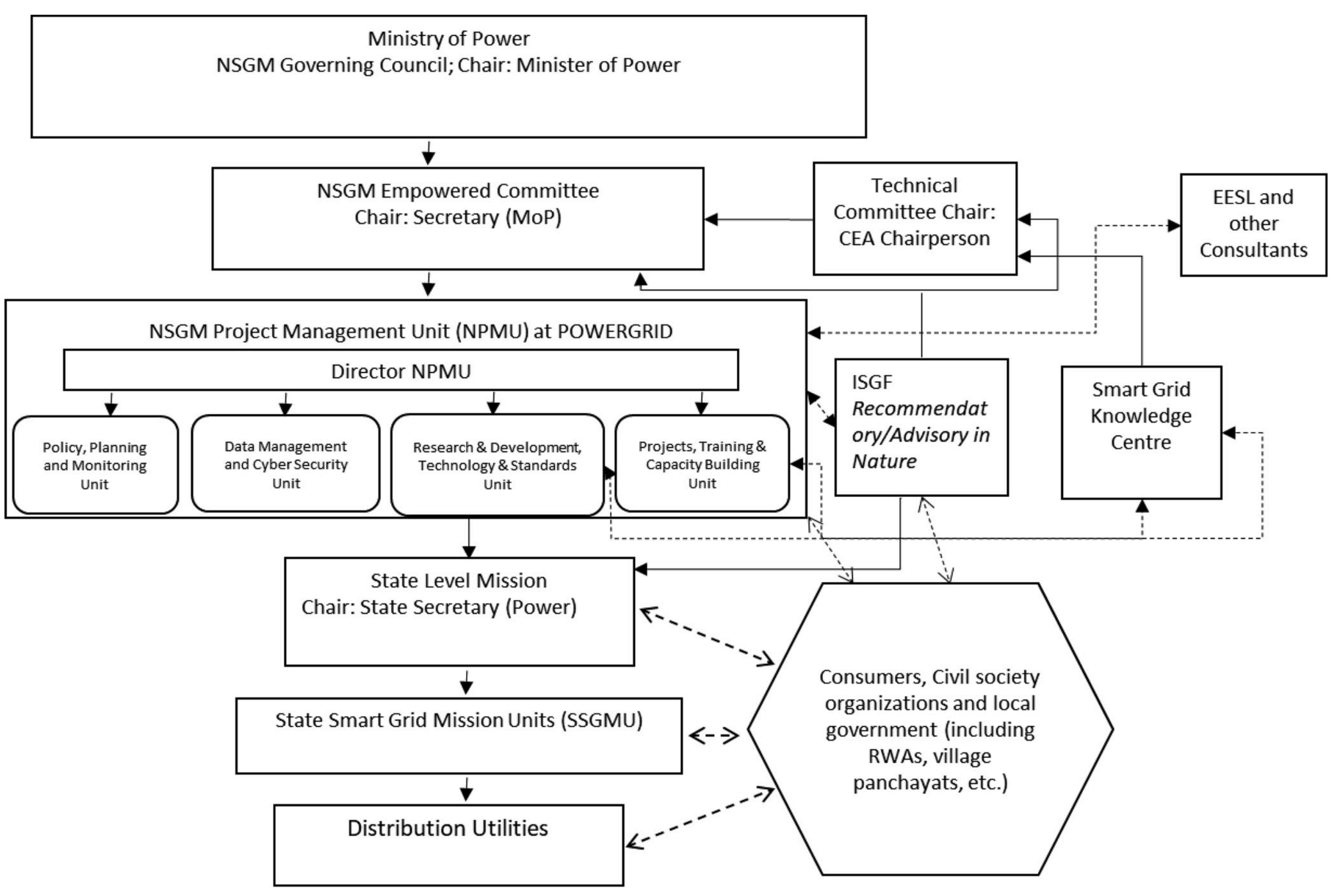

Fig. 3. Govt. of India's smart grid mission framework.

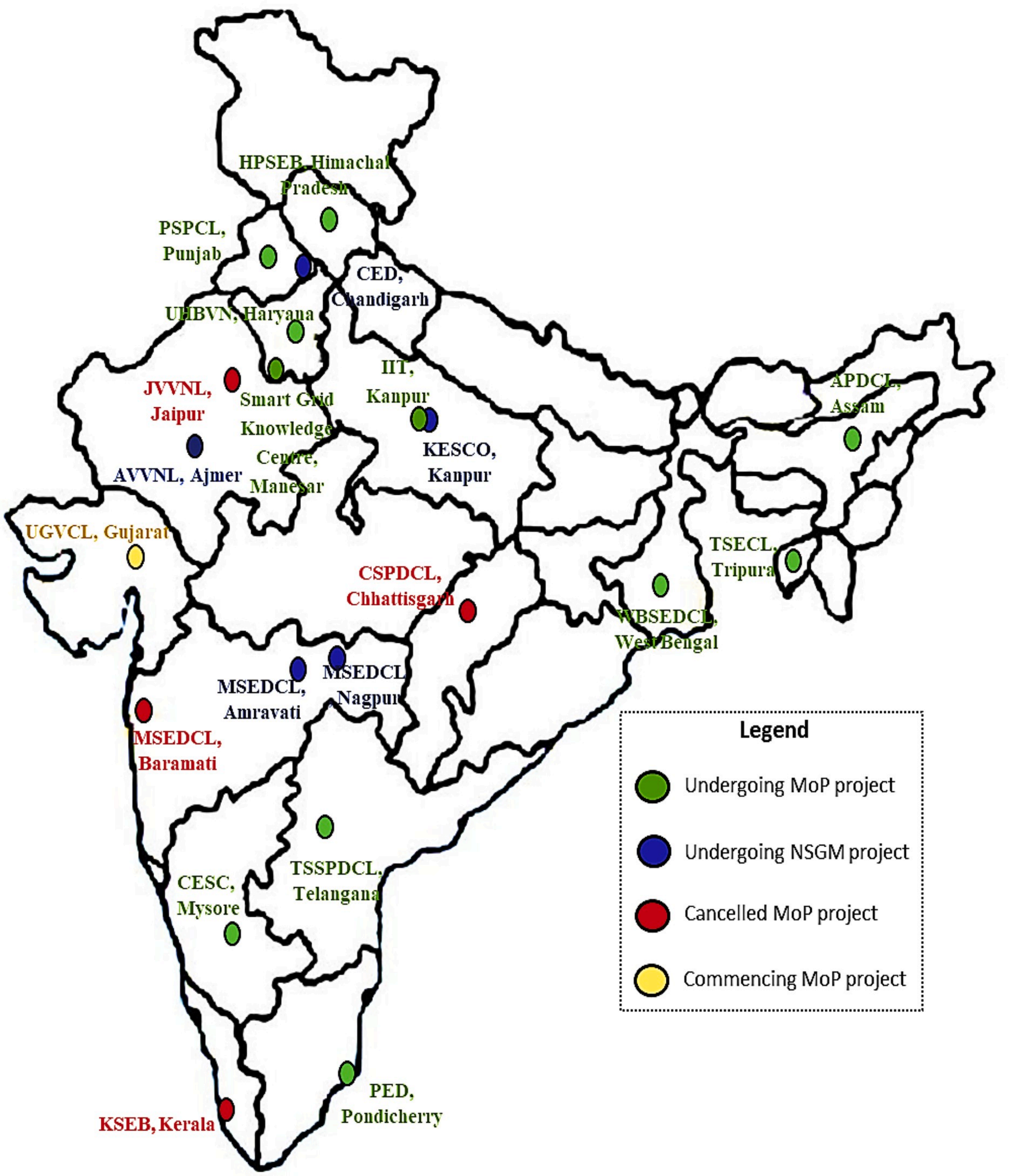

Fig. 4. Ministry of Power's Smart grid pilot projects.

policies and procedures of the smart grid implementation in reference to the different states. As shown in Table 3, some of the functionalities are proposed for implementation in every state. The details of these projects are updated monthly which can be accessed at (Deployingmart City Ne, 2015).

The details of different pilot projects are summarized in Table 4 (Expands Silver Sprin, 2017):

6. Other smart grid projects

Apart from the 16 Govt. of India ongoing pilot projects, various other projects in joint ventures with foreign and domestic agencies, institutions and companies have been launched in India. This section surveys all such projects and briefly lists them. Fig. 5 shows the location of these projects.

Details of these projects are as follows:

UPES, Dehradun

University of Petroleum & Energy Studies is implementing smart grid project in association with BSES Yamuna Power at its Electrical distribution substation (11 kV/415 V) in Dehradun city. The complete project

Table 3
Functionalities to be Adopted in Smart Grid Pilot Projects.

Functionalities → / Pilot Projects ↓	AMI-R	AMI-I	PLM	OMS	PQ	DG	MG	DR	SCADA	Other Functionalities
APDCL, Assam	×	×	×	×	×	×				
CESC, Karnataka	×	×	×	×		×	×			
HPSEB, Himachal Pradesh		×	×	×						
IIT Kanpur Smart City	×					×			×	×
PED, Puducherry	×	×								
PSPCL, Punjab	×	×	×							
Smart Grid Knowledge Centre, Haryana	×			×		×	×			×
TSECL, Tripura	×	×	×							
TSSPDCL, Telangana	×	×	×	×	×					
UGVCL, Gujarat	×	×	×	×	×					
UHBVN, Haryana	×	×	×	×					×	
WBSEDCL, West Bengal	×	×	×							
CED, Chandigarh	×	×								×
MSEDCL, Amravati	×	×		×				×		
MSEDCL, Congress Nagar	×	×		×				×	×	
KESCo, Kanpur	×	×	×			×				×

Table 4
Ministry of power smart grid pilot projects.

Sr. No.	Name of the Utility	Location	Total Project Cost (Rs. Cr.)	GoI support (Rs. Cr.)	Consumer base	Present status
1	**APDCL, Assam**	Paltan Bazar, Narengi, Ulubari - Assam	29.94	14.97	15,083	Project declared go-live on 2 May 2019 with AMI
2	**CED, Chandigarh**	Chandigarh	28.58	8.6	29,433	MDM System under configuration. Data centre works awarded, rest under tendering.
3	**CESC, Karnataka**	Mysore - Karnataka	32.59	16.28	21,824	Project completed
4	**HPSEB, Himachal Pradesh**	Kala Amb Industrial Area - Himachal Pradesh	19.45	9.73	1,251	Project completed
5	**IIT Kanpur Smart City**	Kanpur – Uttar Pradesh	12.5	6.25	–	Project completed
6	**KESCO, Kanpur**	Kanpur – Uttar Pradesh	319.57	95.87	539000	Request for Proposal (RfP) under preparation.
7	**MSEDCL, Amravati**	Amravati – Maharashtra	90.05	27.02	148495	Project under hold. New roadmap under formulation
8	**MSEDCL, Nagpur**	Congress Nagar, Nagpur – Maharashtra	139.15	41.75	125000	Project under hold. New roadmap under formulation
9	**PED, Puducherry**	Puducherry	46.11	23.06	33,499	Project declared go-live on 28 Dec 2018. 28,910 smart meters and 490 DCUs installed.
10	**PSPCL, Punjab**	SAS Nagar – Punjab	10.11	5.06	2734	Failure in supplying smart meters led to cancellation of contract. New roadmap under formulation.
11	**Smart Grid Knowledge Centre, Haryana**	Manesar – Haryana	9.8	9.8	–	Contracts awarded for HEMS, Workstations/Training Room Hardware. Building under construction. FAT for OMS awaited. Quality evaluation for MicroGrid under process.
12	**TSECL, Tripura**	Agartala – Tripura	63.43	31.72	45,290	Project under commercial operation
13	**TSSPDCL, Telangana**	Jeedimetla Industrial Area – Telangana	41.28	20.91	11,906	Project declared go-live on 30 March 2019 with single phase meters
14	**UGVCL, Gujarat**	Sabarmati – Gujarat	82.70	41.35	22,230	Site survey work done. Project inaugurated on 27 Feb 2019.
15	**UHBVN, Haryana**	Panipat - Haryana	131.25	0	11,000	Project completed
16	**WBSEDCL, West Bengal**	Siliguri, Darjeeling – West Bengal	7.03	3.52	5,265	Project completed

Abbreviations.
RTU: Remote Terminal Units; HAS: Home Automation System; HEMS: Home Energy Management System; FAT: Factory Acceptance Test; DRS: Draft Registration Statement; MDM: Mobile Device Management; CT/DT: Current/Distribution Transformer.

is spread over in three stages. The first stage involving incorporation of Modular Integrated Distribution Automation System (MIDAS) for remote health monitoring of equipments and detection of fault location on 11 kV network has already been implemented. It transmits the value of current, voltage, power, energy, oil temperature, oil level etc. from two Distribution Transformers (630 kVA & 750 kVA) over internet through a GSM based modem. Along with reading the data, the modem will also provide information about the status of control room door, fire alarm and short circuits etc. For the second stage, the proposal is about the integration of diesel flow meters with Diesel Generator (DG) sets to avoid any spillage as the diesel consumption will be recorded. This will ensure the optimization of the per unit consumption of diesel. Around 20–30% saving in the diesel consumption can be achieved through this and also reduction in emission in the same proportion. The third stage proposes for the integration of 100 kW solar power plant (of UPES) with the grid for optimizing the utilization of solar power and reduction in the grid load (Tata Power Delhi Distribu, 2016).

CESC, Kolkata

Tetra Tech and ESTA International Inc. are implementing a smart grid project at Kolkata in conjugation with Calcutta Electricity Supply Company (CESC) under a United States Trade and Development Agency (USTDA) grant of $618,860. Approximately 1,000 feeders from 33 kV (kV) to 6.6 kV were selected for a through-voltage profile study. Additionally, for improving reliability of power supply, feeders were

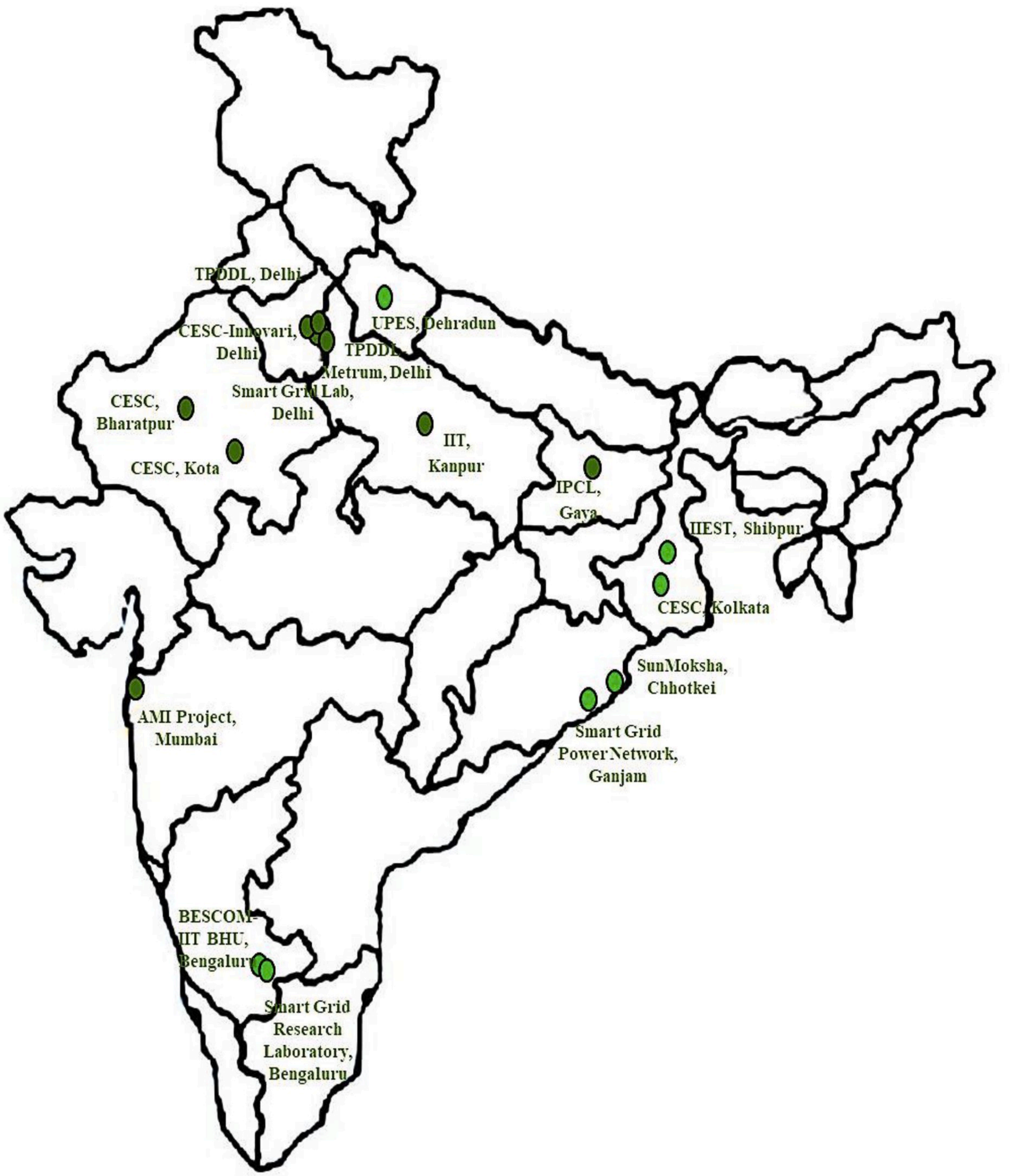

Fig. 5. Other smart grid projects ongoing in India.

identified for volt-var compensation (India Power Corporation Limited, 2015).

For Advanced Metering Infrastructure and Distribution Automation (DA) applications in Kolkata, CESC is going to use Silver Spring's IPv6 public cloud Internet of Things network and data platform. It will be advantageous in improving grid reliability, increasing power efficiency and ensuring billing accuracy. Further, it will enable CESC to access real time status of grid infrastructure to improve grid reliability as well as reduce transmission and distribution losses. Approximately 25,000 customers will be connected and CESC's electricity distribution grid will be automated in the initial phase of the deployment (Brochure- India Power, 2014).

CESC, Kota & Bharatpur

Approximately 187,000 homes and businesses spread across 150 square kms in the Kota franchise service area and approximately 50,000 homes and businesses across 50 square kms in Bharatpur will be connected with Silver Spring's standards-based IPv6 platform to have two-way connectivity. CESC will leverage Silver Spring's powerful analytics engine and user interface which improves working efficiency and develops business processes and workflows which improve billing accuracy and reduce loss in energy (Tata Power Delhi Distribu, 2017).

Smart Grid Lab, TPDDL-

Tata Power Delhi Distribution (TPDDL) has launched a 'Smart Grid Lab' to showcase different basic and advanced operational technologies, information technologies and advantages of combining operational and information technologies. The hands-on demonstration of new technologies, products and operations will be the focus of the lab. The features of collectors, routers, Meter Data Management System (MDMS) and Head End System (HES) as well as the real data obtained from the pilots in service in the field van be viewed by the visitors. Another salient feature of the lab is the Automatic Demand Response (ADR) controllers and systems. For improving the distributed generation and quick load management, these have been implemented on a pilot basis in the TPDDL distribution area. Also included are the automatic demand side management of both critical and non-critical loads at building-level, addition of solar based generation and energy storage, and islanding mode micro grid formation. The aim of this smart grid lab is testing and operationalizing the implementation of advanced technologies before the deployment in the field. Another purpose is to serve as a forum for demonstrating the advanced technologies to national and regional regulators, state discoms, etc. (Ahmadet al., 2019)

IPCL, Gaya

India Power Corporation Limited (IPCL) signed a partnership agreement with USTDA on 30 August, 2016 in New Delhi with aim to implement smart grid technologies at its Gaya Distribution Franchise (200 MVA) in the state of Bihar. Usage of smart grid technologies will result in a higher degree of efficiency, reliability and customer service. Tender has been floated for the US based firm only to assist IPCL and $593,400 grant is allocated for this project by USTDA (Ahmad et al., 2018).

IPCL has already initiated the first phase of the Smart Grid Project. In first phase, Automatic Meter Reading Project (AMR) was successfully implemented. Consumer Meter Reading Reports and bills are now being generated in real time and variance in data is negligible. This has resulted in increased operational efficiency by savings in lead time for bill generation & meter reading. Now second phase of the project is being implemented which will ensure management of data in real-time and availability at receiving feeders, enabling Transmission and Distribution Loss Management (Shaikh et al., 2018).

TPDDL-IBM, Delhi

TPDDL in collaboration with IBM has successfully implemented a large-scale AMI and ADR project which connects 165 commercial and industrial consumers with load above 100 kW. 7 MVA of Demand Response curtailment was achieved by carrying out 6 ADR events in the months of May and June 2014. Smart Meters and AMI including integration with: Meter Data Management System (MDMS), Head End System (HES), etc., Automated Demand Response were successfully demonstrated with this project. Sub GHz RF, Enterprise Service Bus (ESB) and 3G Communications technology have been deployed for the integration (Tata discom selectsM f, 2013).

TPDDL-Landis + Gyr, Delhi

TPDDL has launched a smart grid project in partnership with Landis + Gyr involving setting up of radio frequency mesh communication project in its licensed area of 510 sq. km in north and north-west Delhi. The project will help Tata Power-DDL to provide greater service options to customers and accurate information on their energy consumption patterns, helping them to manage their usage more efficiently and improve overall reliability by reducing outage time. The project will also help in enhanced monitoring and control points throughout Tata Power-DDL's network on real time basis and will aid in reduction of commercial losses. The collaboration also includes deployment of 2 million end-points, comprised of communication card for smart meters and automation of operational applications and integration with current and future applications like Advanced Distribution Management System (ADMS), SCADA, etc. (Ahmad et al., 2019).

TPDDL-Metrum, Delhi

TPDDL implemented a smart grid project of Intelligent Power Quality Management solution in association with Metrum, a Swedish company on 7th October 2016. This project will help in monitoring power quality issues created by various loads including electronic appliances at select locations in Tata Power-DDL network at voltage levels of 66 kV, 33 kV, 11 kV and 415 V. The system implemented include sensors on the electrical network and software at server systems for checking power quality parameters, power factor, harmonics etc. and monitor them through web solutions and its integration with other systems. Overall, the monitoring solution will help to improve reliability of the distribution grid, improve quality of power, increase asset life, reduce power outages and provide better grid management. The solution will also help Tata Power-DDL to fix technical problem in real time, aid in preventive maintenance, prevent energy losses and plan the integration of solar PV into the distribution grid in an efficient way when there is an increase in rooftop PV and Electric Vehicle penetration apart from improving energy efficiency at the grid level (Ahmadet al., 2019; Ahmad et al., 2018; Shaikh et al., 2018; Ahmad et al., 2019).

CESC-Innovari, Delhi

CESC Limited with Innovari Inc. has implemented a technology platform that enables CESC to partner with their customers to enable and dispatch any edge of grid resources, such as advanced control of customer loads and distributed energy resources at customer premises. This project has enabled the customer owned generator set to be synchronously connected to the grid for the first time in India. This pilot project of 1.5 MW was inaugurated on August 29, 2016 in Delhi by remotely synchronizing the DG set at a CESC customer's site in Kolkata from instructions given in Delhi. The project utilizes Advanced Demand Side Management (ADSM) as well as Distributed Generation (DG) resources to enable new capacity, helping to reduce the any requirement for power outages and improve system utilization. This project serves as a model for other utilities the capability to integrate "dormant" capacity available at customer premises into the grid economically, safely and reliably (Ahmad and Alam, 2019).

SunMoksha, Chhotkei

Chhotkei is a small village in Angul having population of 600 villagers living in 140 households spread over 235 ha of land with no grid electricity. The energy demand of the village comprising of 140 households, 20 streetlights, a temple, and three community centers which consume about 20 kW is fulfilled by a 30 kW solar powered smart Nanogrid. The remaining 10 kW is kept aside for usage by irrigation pumps and microenterprises such as stitching, poultry, provision stores, rice-puff machines, oil mill, refrigerators, welding machines, etc. during day time to generate employment, improve agricultural output, and enable value-addition to agriculture. Power is distributed to the consumers through the pilferage-proof distribution and control system of the Smart Nanogrid spread throughout the village. Communication to controllers and meters from the local server at the power plant control room is done through fiber optic cables. The billing, metering and payment, alerts and cut-off in case of non-payment, and differential tariffs for irrigation, household and business is done by smart Nanogrid. Demands of street lights, irrigation pumps, microenterprises etc. is also scheduled by it. The microenterprise load is scheduled to match the solar generation profile. When a consumer exceeds the allocated power or energy, the system switches off the power supply. The measurement of the moisture of the soil decides the irrigation time and amount. The demand and supply constraints are balanced by these measures. It also manages all customer information, technical support, continuous training, and local value add services to consumers. The capital cost for Smart Solar Nanogrid has been funded by a MNC, under their CSR funding. SunMoksha along with Kotak Urja has implemented the project. SunMoksha will provide technical support for O&M and its remote management system, throughout the life of the project [72].

IIEST, Shibpur

Indian Institute of Engineering Science and Technology (IIEST) has successfully created a smart grid pilot project which generates energy from the renewable sources. 32 kW of total power is planned to be generated from the solar, wind and vegetable waste subjected to the availability of the waste products and the favorable weather conditions. The power to be generated from solar energy depends on the availability of sunlight while wind energy will be produced during northern western and tropical storm (Ahmad and Alam, 2019).

BESCOM-IIT BHU, Chandapura

Mindteck in synergy with Indian Institute of Technology (BHU) will implement a smart grid project at Bangalore Electricity Supply Company (BESCOM). This project is research oriented project and aim is to design and develop an energy storage integrated smart grid architecture. The funding of this project is by the Department of Science and Technology (DST). The project involves the installation of Advanced Metering Infrastructure (AMI), DCUs, LT-CT and HT-CT operated-meters, single phase and three-phase smart meters, Meter Data Acquisition System (MDAS) and Meter Data Management System (MDMS) for acquiring and retrieving real-time data. Through this network, the consumers can monitor their usage of energy. Also, information about the power supply availability and tariff structure for heavy appliances will enable the consumers participation, which is a crucial characteristic of Smart Grid Infrastructure (Asaad et al., 2018).

7. Challenges, research avenues and potential solutions

The challenges in implementing smart grid in India are very much the same as faced during the power sector reformation including market liberalization commenced nearly two decades ago. Huge transmission losses (~20%), voltage fluctuations, chronic blackouts in rural and semi-urban areas, brownouts in urban areas, lack of electricity supply in far ruler areas are persistent challenges yet to be resolved. Apart from these infrastructure/operation-based challenges which are common in the Indian power sector, the unique challenges related to smart grid deployment in India are enumerated below:

- Nationwide smart grid implementation plan lacks in commercial viability aspect. Basic infrastructure upgradation and better management seem to be more imminent challenge for now e.g., reduction of high transmission losses.
- Lack of coordination between stakeholders for smart grid deployment e.g., monopoly and draconian laws by few state government electricity boards over power generation and distribution in their respective jurisdiction.
- Poor financial condition of state owned power companies. Static electricity pricing, bill defaulters, corruption, mismanagement are the primary cause of this.
- Non-driven efforts by state owned T&D companies to upgrade power delivery infrastructure due to low appreciation for technological developments in the power sector.
- Inadequate skill and knowledge of personnel to operate new devices, new systems, new communication technologies. Absence and low quality of personnel training programs poses further challenges. Privacy and security issues especially pertaining to consumer and critical data.
- Due to non-maturity of technologies involved in smart grid, significant capital costs are there and cash strapped state electricity boards face financial challenges in implementation.
- Lack of public awareness and consumer knowledge programs results in low consumer acceptance of dynamic tariffs & pricing and participation in demand management which is integral part of the smart grid.

Vast technological and financial investments obligate the phased manner implementation of smart grid, considering the diverse needs of the utilities, regulatory environments, energy resources and existing system. Some solutions for Government of India to overcome the barriers in smart grid deployment are suggested below:

- Providing technical knowledge and assistance to utilities related to involved technologies and equipments.
- Adopting privacy and security measures to protect and handle sensitive data.
- Detailed and organized national road map for smart grid implementation addressing concerns of state and private players.
- Clear and simple policies to facilitate the interstate power transmission and participation in power market exchange.
- Fiscal support to state utilities and enforcement of penalties for non-performance.
- Creation of research avenues in the following:
  - o Development of state-of-the-art power sector technologies adhering to Indian sub conditions e.g., climate through domestic efforts and foreign collaborations.
  - o Programs to increase awareness among consumers about advantages of smart grid thus enabling their participation in demand side management and demand response.
  - o Exchange of knowledge and shared experiences of smart grid deployment and challenges faced by countries of similar nature already adopting smart grid.
  - o Feasibility of different smart grid technologies e.g., demand side management, power market exchange etc. in diverse contexts of Indian power sector

8. Conclusion

The ageing, inefficiency and non-reliability of present utility grid has created a requirement for its modernization and upgradation. With the integration of smart devices and Information & communication technologies, the smart grid presents a sustainable choice for delivering more efficient and consistent power, along with a plethora of advantages over the existing grid. As electricity is a basic requirement of economic growth, transformation of existing dumb grid to the smart grid should be a significant strategy for the governments. With India poised to be a global energy superpower, the smart grid is going to be a significant driver. But deployment of smart grid requires India to successfully overcome challenges such as customer awareness and acceptance, ample funding, necessary expertise and knowledge, amendments in existing policies and regulatory frameworks, security threats, etc., to implement a smart, secure, consumer affable and sustainable electric grid.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2019.101499.

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