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Review

Challenges and issues of smart grid implementation: A case of Indian scenario

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Abstract

Smart grid (SG) is emerging as a new facet of power industry. It incorporates numerous advanced technologies to deal issues prevailing with conventional electric networks. Though capable to resolve many of these issues, SG is still facing challenges in deployment. These challenges are associated with adaption of emerging technologies, socio-economic issues, lack of policies and awareness. Since Government of India (GoI) has initiated nationwide deployment of SG projects, the objective of this paper is to identify challenges and issues in SG implementation. In such situation, it is primarily essential to identify and discuss the barriers to overcome deployment concerns, including consumer's acceptance. In this paper, such major challenges and issues for SG implementation have been encapsulated. Considering the vision and roadmap of the Indian SG, an indicative assessment framework has been developed and details are discussed here. A case study of solar PV awareness survey has also been presented to understand consumers' interest and concerns toward components of SG.

Keywords: Smart grid; Clean energy; Grid infrastructure; Indicative assessment; Regulation; Policies

Contents

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Nomenclature:

SG	smart grid
SGCC	Smart Grid Consumer Collaborative
GSFG	Global Smart Grid Federation
GoI	Government of India
UK	United Kingdom
U.S	United States of America
GW	Giga Watt
PGCIL	Power Grid Corporation of India Limited
PED	Puducherry Electricity Department
REAP	Renewable Energy Agency of Puducherry
MoP	Ministry of Power
GoP	Government of Puducherry
MNRE	Ministry of New and Renewable Energy
NGO	Non-Government Organization
RTS	roof top solar
MG	micro grid
PV	photo voltaic
ICT	Information and Communication Technology
CFL	Compact Fluorescent Lamp
LED	Light Emitting Diode
INR	Indian Rupee
TV	Television
IT	Information Technology
K	kilo or thousand
DR	demand response

kV	kilo volt
kVA	kilo volt ampere
kVAr	kilo volt ampere reactive
VAr	volt ampere reactive
KWh	kilo Watt hour
MVA	mega volt ampere
EV	electric vehicle
GPS	global positioning system
GPRS	General Packet Radio Service
PLCC	Power Line Carrier Communication
AT&C	Aggregate Technical and Commercial

1. Introduction

Over the decades, power system has grown into gigantic network, which spans the globe to meet thriving electricity demand (Anon, n.d.). A report from Global Smart Grid Federation (GSGF) claims that existing power grid networks are not equipped enough to meet demands of 21st century parameters viz. quantity, quality, efficiency, reliability, ecology and economy (SmartGrid Canada, 2012). These led a paradigm shift of centralized power generation based electric grid toward the decentralization (Smart Grid Bulletin, 2015). Today's power situation plays a welcome role for SG as it considers efficiency, reliability, economy and other crucial parameters besides optimally utilizing the available power resources (US DOE, 2010; El-Hawary, 2014).

SG foresees a bright future to stakeholders, consumers, regulators and others which is evident from several pilots of SG projects across the globe. Analysis by different groups under U.S. department of energy initiative (US Department of Electricity, 2012) claims a peak load reduction of 0.75–1.2 kW per consumer. In smart city of Queensland, Australia, it has been recorded 46% reduction in both peak demand and electricity consumption by June 2012 (VassaETT, 2013). As per the studies of ISO/Wholesale markets in US, Demand Response (DR) contribution to peak load reduction has been increased by 10%, since 2006 (EPRI, n.d.). Through utilization smart meters for DR and variable pricing programs, California state is envisaging peak load reduction of 100 MW. The smart grid 2013 global report claims, through a survey of 200 SG projects, 70% of pilots have experienced enhanced reliability up to 9% (VassaETT, 2013). Studies have also demonstrated that SG can be made self-healing and resilient. Smart grid offers a great deal to economy also, as analyzed in Yu et al. (2011) which claims that UK can save £19 billion net present value (NPV) on SG investments between 2012 and 2025, if opted for upgradation to SG rather than augmenting in conventional ways. Further, SG has a potential to support 12,000 jobs annually in UK alone (Easton and Byars, 2012). Duke Energy in Ohio has reported saving of $10.18 per customer per year in special meter reads and additional $3.5 saving per customer per year on non-labor expenses such as meter testing, repairing and replacement. Smart Grid Consumer Collaborative (SGCC) claims to find a benefit of $2.00–$19.98 per customer per year through Time of Usage tariff. SG facilitates optimal planning, scheduling and maintenance of all types of power generators and storage units thereby reducing operational and capital costs. Apart from direct savings, SGs also facilitates for integration of secondary power sources viz. Electric Vehicles, Renewables, Thermal and Distributed Generation. SG thus provides direct benefits to consumers through.

- Saving from restructured tariff.
- Reduced duration and frequency of power outage.
- Ability to become more energy self sufficient.
- Benefits in terms of home automation and electric vehicle.

In the case study of Boulder, Colorado, SGCC found that consumer power quality complaints have been reduced to zero, from an average of 30, post implementation of SG (Smart Grid Consumer Collaborative, 2013). Some authors (VassaETT, 2013) claimed enhanced customer satisfaction up to a range of 70–90% while Jonathan and others in (Wang et al., 2011) reported that 90% of consumers have enhanced satisfaction through data collected from six case studies. Consumers' appreciation has also been noticed after implementation of SG, with enhanced ability to monitor their usage through web portal (Wang et al., 2011). Involvement of customers in business through SG has made them more aware and led to active participation. SGCC has conducted four rounds of consumer survey in U.S. which conveys that (Non-Member Summery, 2014):

- Besides the paucity of awareness, consumer interest in SG is very high, although the same does not reflect in program participation and technology adaption.
- Consumers understand the importance of clean energy as well as grid reliability and hence they are willing to pay more if needed, to accept them.

Analysis proves that besides providing technical and economic benefits, SG is also environment friendly. Analysis of top 30 projects across the globe claims, strong environmental impact is a factor of consumers' behavior and their nature of consumptions, as per impact report in VassaETT (2013).

SGCC claims reduction of 372 pounds of CO_2 emission reduction per consumer from Volt/VAr control using U.S. environmental protection agency estimate on CO_2 equivalent estimate per kWh. Further they also estimated CO_2 emission reduction of 11–110 pounds per customer per year from time-varying rates using the same kWh equivalent as earlier (Smart Grid Consumer Collaborative, 2013). Greenhouse gases have been reduced to 54,000 tons by June 2012 in smart city of Queensland, Australia (VassaETT, 2013). Over all, it is well understood by utilities, stakeholders and participants that smart grid is associated with renewables that would reduce the pollution through clean energy production.

Indian scenario is not much different from rest of the globe (Kappagantu et al., 2016; Balijepalli et al., 2009; Balijepalli et al., 2010). India has the world's largest single synchronous grid, with around 300 GW of installed capacity and expecting to reach 900 GW by 2032 (Madan et al., 2007; MoP, 2013a; Power Sector, 2015; Manas, 2015). To enhance the performance and reliability of the grid and also to support technical, economic and social development, India is adopting SG initiatives like; "Smart Grid Vision and Roadmap for India", "National Smart Grid Mission", "Nehru National Solar Mission", etc.; (MoP, 2013b; MNRE, 2015a; MNRE, 2015b).

Regarding significance of SG, as a marketing term rather than a technical term, several definitions, importance and technologies are discussed in detail (IEC, 2018; GSGF, 2018; Office of Electricity, 2018; ISGF, 2018; Albano et al., 2015; Unterweger and Engel, 2015; Misra et al., 2014; Kappagantu et al., 2015a). There are several ongoing global efforts that are put across the world for developing SG (ISGAN, 2016). Power industry is embracing higher versions of technology like smart grids to meet the obligations of 21st century. Now with support from all stakeholders of power sector, SG success is possible but need to overcome few challenges. Like any other technology, SG also has to face certain technical, social and economic barriers. Technical challenges are basically bottlenecks in the integration of several devices with grid network. While economy is the primary factor for developing any technology, social acceptance also becomes crucial for its success. Considerable acceptance of technical advancements have been achieved in SG but still there are issues that need to be addressed. Grid infrastructure is inadequate in several power pockets, cyber security is a very complex issue for utilities and other technical issues like storage and stability are also of high importance seeking speedy resolutions which poses greater demand for SG research (Chandrasekaran, 2012; Amin, 2011; Arnold, 2011; Guo et al., 2015). Not only the technical challenges, but issues on social and economic frontier too appeal for concern.

This paper encapsulates the discussions on major challenges in implementation of SG. Starting with this introduction, the paper is arranged in a manner that initially discuss the technical challenges followed by socio-economic issues. Later, miscellaneous issues in implementation of SG technology are addressed, followed by a case study of solar PV awareness survey with a conclusion chapter at the end.

2. Technical challenges

2.1. Inadequacies in grid infra structure (Chandrasekaran, 2012)

In developing countries like India, the grid infrastructure is still evolving. The existing grid network is inadequate to accommodate the upcoming needs of clean energy and distributed generation which may throw several challenges in design, erection, operation and maintenance. Besides focusing on SG, there is also a need to address issues of existing grid infra structure. In India, several electrical parts of country are unevenly connected to national grid in order to optimally evacuate large wind farms or solar parks which otherwise demand for installation of entire infrastructure. In this context, it is good to learn that Government of India is taking all possible and positive measures to overcome the Grid operation and connectivity problems through its working arms Central/State Transmission Utilities and National/Regional/State Load Dispatch Centre.

2.2. *Cyber security (Amin, 2011; Aillerie et al., 2013; Wang and Lu, 2013)*

Connecting grid to cyber network triggers numerous vulnerabilities in the system and regrettably we are unaware about them. Recognizing and eliminating such loopholes before any security breach happens is very essential. Mainly three objectives of cyber security in SG have been addressed and discussed in Kappagantu et al. (2015a), i.e. availability, integrity and confidentiality. Availability refers to reliable and timely access to database and other information; Integrity includes protection from improper format/modification/destruction of information; Confidentiality refers to security of information from unauthorized access. Cyber security is one of the substantial issues for operation, since any single loophole has a potential threat to turn into disaster for utilities and individuals involved with grid. Well known cyber threats are hackers, zero day, malware, etc. Provision of any security feature alone is not sufficient enough to tackle such threat of logic bomb on grid. Infact smart grid has a multilayer structure and each layer demands for specific security concerns. There is no silver bullet for cyber threats but it mandates the development of advanced techniques for tackling the ever-evolving sophisticated cyber threats.

2.3. *Storage concerns (Reynolds and Mickoleit, 2012; Lindley, 2010; EES, 2017)*

SG incorporates renewables for bulk power as well as distributed power generation. As the power generation from renewables is not uniform i.e., intermittent and variable, they may demand storage. Battery, the most common storage device, has very short life span of 4–5 years. Other storage technologies like flywheels, thermal storage, hydrogen storage, etc. have their respective varying concerns. Pumped storage technique, which is in regions of US, China, Japan, India and Norway, have efficiencies in the range of 70–85%. The problem with pumped storage techniques is that, it requires large areas as reservoirs which are normally available in mountain side only. For significant growth of SG, this option requires to move away from Pumped Storage in the mountain ranges. Research on its hybrid system with offshore wind is underway. In few regions of Germany storing compressed air in underground storage is in practice too, which can be used for electricity generation when needed. Although efficient, the complexities of storage facility become a hurdle for this technology. Flywheel is capable in absorbing energy in few seconds and delivering back quickly. Researchers found that Flywheels are very useful for supporting grid frequency for few seconds but they are not stable for longer duration. The most common technique for electricity storage is batteries and among them lead-acid batteries are the most popular. Portability is their advantage but low energy density, weight and size are the concerns for innovators to research. Further, risk of shortage of raw material for batteries is also a serious issue. Research on increasing efficiency and reducing cost of storage technologies is going on, but still battery storage technologies are expensive. Advanced Lead Acid Batteries, Flow Batteries and Lithium Ion Batteries are the options being tried in SG project in India for large scale storage purpose. At Puducherry, as per REAP provisions, the two commonly available configurations are rooftop solar PV system with and without battery back-up Figs. 1 and 2 which are very user friendly and needs no technical expertise.

2.4. *Data management (Arnold, 2011; Software, 2012)*

SG infuse power network with enormous quantum of meters, sensors and controllers. The data from these units and from other sources like weather forecast, security cameras, etc. enhance the capability of operators. Through accurate analysis of data, a breakdown or damage could be avoided before occurrence. Further this big data could be utilized for system operation, alarms, forecasting demand, generation, price, etc. The data so collected is really big in volume, for example from employing smart meter that enables reading at each 15 min instead of once in a month increases the data almost 3000 times. Voluminous data from these devices is not only difficult for collection and storage but also poses critical challenges in retrieval and handling. Database management is a vital issue in SG. High volume of data may slow down the process of data collection, analysis and report generation.

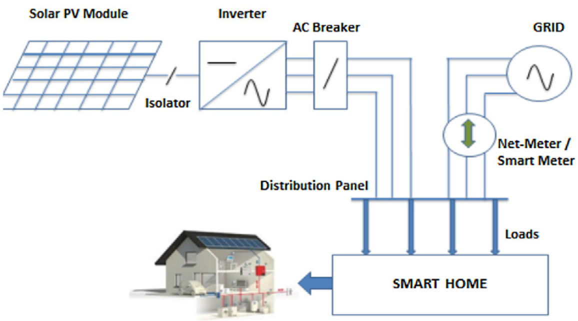

Fig. 1. SPV system without battery back-up.

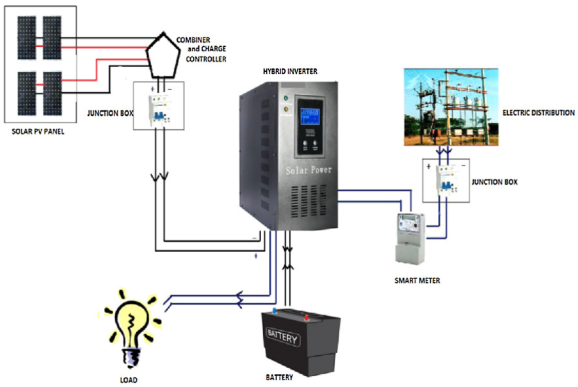

Fig. 2. SPV system with battery back-up.

Apart from developing technology to manage the data, defining standards and protocols are of utmost importance and also necessity. Cloud based technologies may help in big data handling and analysis.

2.5. Communication issues (Gungor et al., 2011; Ma et al., 2013; Fang et al., 2012)

We have a wide range of communication technologies for deployment in SG but they all have their own limitations. One technology has limited bandwidth while the second operates in limited distance, third has higher data loss and other has limited success in underground installations. Thus, despite numerous advantages, communication technology for SG still lacks a fool proof solution. Communication protocols are not well defined in SG network. Few technologies of this category are GSM, GPRS, PLCC, 3G, ZigBee, Broad band over PLC, etc. GSM and GPRS have coverage range of upto 10 km but they lack in data rates. 3G requires costlier spectrum, whereas ZigBee is limited by coverage range of 30–50 m only. Wired communication like power line communication overcomes the issues of wireless communication but face the problem of interferences. Optical fiber is fast and secure but is very expensive too. Router based RF technology with a canopy may solve the problems to some extent but it again lacks the history of proven in situ performance success stories besides the economy issues.

2.6. Stability concerns (Gopakumar et al., 2014; Kappagantu et al., 2015b)

SG is supposed to incorporate distributed generation (Renewables) and micro grids (MGs) on a large scale. The distributed generation causes bidirectional power flow. Renewables have various advantages over conventional and nuclear energy sources but high penetration of renewables and MGs would raise stability concerns like:

- Angular stability due to lower overall system inertia.
- Voltage stability due to lower power sharing support.

- Low-frequency power oscillation.
- Worsening of SG transients profile during MG islanding.
- Inability to serve as system reserve.

2.7. Energy management and electric vehicle (Li et al., 2014)

Using electric vehicle (EV) as storage prospective is on proposal. Research for efficient utilization of electric vehicle during periods of peak hour is going on. Batteries of EV can be charged in off peak period and can be used as source during peak periods (Software, 2012). Few basic controls in managing energy through EV include:

- Flow of power from
  - vehicle to grid (V2G),
  - grid to vehicle (G2V),
  - vehicle to vehicle (V2V).
- Reactive power control.
- DC link voltage control.
- Grid voltage support.

All these controls are not well defined yet and are still evolving. Development of standards for these is also on the anvil.

3. Socio-economic challenges

Socio-economic scenario plays a vital role in implementation and success of any technology. A technology becomes irrelevant if it fails to attract the investors or users, leading to failure of pilot projects, rejection of new technology, etc. Sometimes such issues may arise as a result of some economic or technological and some sometimes due to lack of appropriate awareness among stakeholders. Following are some discussions on few major issues in this regard (El-Hawary, 2014; Chandrasekaran, 2012; Guo et al., 2015; Wang and Lu, 2013; Gupta, 2012; Sinha et al., 2011; Kappagantu et al., 2015c):

3.1. High capital investment

With high initial investment involved, SG is beneficial from economical perceptive that is realized on a long-term basis besides several technical advantages that it offers. Due to this initial capital investment in SG technology that appears to be high and the prevailing Indian conditions with inadequate financial health of Indian power utilities, SG deployment in India poses a major concern. Hence, awareness programs and incentives are essential to encourage utilities, organizations and individuals; to understand the SG benefits and cost burden. Merger of government, utilities and other sectors for sharing the initial burden could be a way out to build the business model.

3.2. Stakeholder's engagement

New technology, high capital investment, lack of accurate information, etc. leads to negative perception of stakeholders that can derail even the SG project despite the highest potential benefits it offers. Advocate of smart grid should identify SG benefits to induce faith factor in stakeholders.

3.3. System operation aspects

Different operational aspects such as billing, tariff structure and operational strategies are some factors of utilities that may influence the SG deployment. They mainly depend on policies, participants, mindset of consumer, perception of operator, and state of supporting elements, etc. which vary with time. Defining any unified guidelines for operation of system is irrelevant and a flexible approach is needed from place to place for SG deployment.

3.4. Lack of awareness

Educating people about SG is much essential for its acceptance. To induce the faith for acceptance, society needs to be aware of SG. Myths create hurdles for any technology. Along with SG installation, utilities also need to focus on consumer awareness programs to teach about power delivery system and role of SG in building economy and efficiency. Consumers are also to be informed about economic and environmental benefits of the technology. Policy makers and regulators also need appropriate awareness; they must be clear about present and future scenario of the technology. Scrutinizing and feedback of awareness activities may also be considered.

3.5. Privacy

Inadequacy in vigilance of huge data handling poses a risk of potential consumer privacy. Safety and security of consumers' information is of utmost concern. Breach of privacy of consumers' information may occur as consequence of any cyber threat or lack of proper policy as well. To maintain faith of consumers, their privacy must be kept intact through cyber security as well as tough regulations. Hence complete assurance to maintain consumer's trust is required for acceptance of SG like technology.

3.6. Fear of obsolescence

Very recently, user of smartphones, computers, etc. have witnessed the rapid growth of technology. Consumers are well aware of how fast these new technologies are becoming obsolete despite the additional benefits they bring forth. Further consumers are also aware that the higher costs associated with these new technologies eventually comes to their shoulders only. Such experience from IT and communication industry could become a road block for SG, if not addressed appropriately.

3.7. Fear of electricity charge increase

Because of awareness paucity, consumers apprehend about the rate increase of electricity charges due to SG deployment. They believe that because of integration of new technology, associated with other factors the tariff would increase eventually. Consumers are also not well aware about new tariff approaches pursued by the utilities and government.

3.8. New tariff

New tariff scheme like as real time use, time of use, critical time pricing, etc. have proven advantages in efficiency from operator's perceptive but each and every consumer may have his own opinion about it. At present, consumers who are comfortable with existing scheme are not in general accepting the new scheme willingly. The low tariff at off peak loads is attracting some consumers but consumers who are liberal in their usage of electricity are in opposition of tariff hike in peak periods.

3.9. Radio frequency (RF) signal and health issues

Few consumers, medical groups and NGOs have registered their concerns about RF signals transmitted from the SG devices and their impact on the health. However, no accurate data is available in this regard, either in favor or against of such claims. A detailed research and awareness initiatives are required to deal with such issues.

4. Miscellaneous

Other than technical and socio-economic challenges there are few more issues that demand concerns from some general perspectives. For example, policy makers, regulators and legal need to understand the technical as well as social aspects of the technology. Few important issues of this category are discussed (Arnold, 2011; Guo et al., 2015; NIST, 2012):

4.1. Regulation and policies

For newly implemented SG, meticulous regulations and policies are essentially required for all stake holders to take active part, which are still under development and in pipe line. Many countries have launched their roadmaps and policies regarding SG. Defining new polices to facilitate SG along with amendment to the existing ones and that too in a time bounded fashion is the need of hour. Framework must be designed in a manner to maximize contribution from all sectors. Risk must be shared with every stake holder across the value chain. The regulations and policies must consider:

- Cost share among the consumer, utility/investor and government.
- Incentives to promote SG.
- Define roadmaps and standards.
- Define the target and coherent time frame.
- Meet expectations of every sector involved, including consumers.
- Legitimate focus on work force creation and awareness initiatives.

4.2. Power theft

In developing countries like India, metering, billing and charges collection is not well structured and so power theft is a very serious concern. There is no wonder to note that in such countries or utilities, the AT&C losses are pretty high. Not only technical and regulatory measures but the social consciousness is also needed to tackle such situations. Social initiatives to change mind-set of individuals involved in such unethical practices is needed in conjugation with enforcement of law and regulations. From the SG Pilot of Puducherry, it is learnt that at least 10–12% improvement on AT&C losses has been achieved.

4.3. Work force

It needs realization that SG is a factor of expertise of workforce on and off the field. Being in evolving phase, smart grid faces scarcity of expert working force. Empowering human resource of different sectors and stake holders through appropriate training sessions for their respective responsibilities characterize the success of SG technology. However, there could also be little threat that existing workforce operating the conventional distribution system like meter readers, line and substation maintenance crew are likely to show resistance for such automation and transparency consequent to SG.

4.4. Co-ordination

Smart grid is a collective enterprise of power, information and communication industries, policy makers, system operators, regulators, government, utilities, manufacturers, business market, economists as well as consumers. A serious concern is that, expert of one sector is oblivious to other domains. Individuals from economics are illiterate about ICT, while the individuals from ICT are not cognizant about Grid scenario. With such baffling circumstances, proper coordination among different parties is very vital. An understanding and well knitted co-operation must be developed to tackle the issues.

5. Indicative assessment

Based on the technical challenges, the vision and roadmap of India smart grids (Kappagantu et al., 2016), an indicative assessment framework has been developed in this section. Fig. 3 depicts such an assessment having options to quantify the impacts, and requirements for deployment of smart grids in India.

The qualitative ranking is provided by using “++” (very strong), “+” (strong), “o” (neutral), “—” (weak), and “–” (very weak), with “++” referring to strong driver for the deployment of specific options in India and “o” representing neither drivers nor barriers.

Options

		Load control switches	Integration of renewables	Prioritization of loads	Improved T&D Infrastructure	DC Microgrid	Time-of-use pricing	Data management services	Smart appliances	Wide-area monitoring and control	Distribution automation	Innovative mobile services	EV and storage to grid
Requirements	Generation & Supply	-	++	o	+	o	+	+	+	-	o	o	-
	Consumers	+	o	+	o	+	+	-	+	--	o	++	o
	Operational Aspects	o	+	o	o	o	+	++	o	+	+	-	o
	Socio-Economic	+	++	+	+	o	+	+	o	-	-	++	+
	Environment	+	++	+	o	o	+	o	+	-	-	o	+
Requirements	Technical Complexity	+	++	+	o	o	+	o	+	+	+	o	+
	Investments	o	+	o	--	+	-	+	o	++	+	o	-
	Human Capacities	-	--	o	o	+-	-	+	o	+	++	+	+
	Policy, Regulation & Standards	++	+	+	-	o	+	o	o	-	o	+	o

"++" strong driver "o" neither driver nor barrier "--" strong barrier

Fig. 3. Assessment framework for investigating the impact of smart grids.

For example, renewable integration and micro grids in India have great impact on environment and generation requirements in smart grid. Because of its wide variability, intermittence and prevailing unpredictability, RE penetration poses challenges not only in environment and generation integration but also in bringing the required regulatory and T&D infrastructure needs.

The load control mechanisms, load prioritization and time of use pricing emphasizes strong requirement of Policies and Regulations from Regulators, Government and Utilities. Similarly, the Smart Appliances, Data Management and innovative Mobile Services do mandate very strongly the cyber security needs and reliable communication technologies. Regulatory role with regard to T&D improvisation, distribution automation and introduction of EV and storage technologies is very crucial in identifying the needs for such upcoming consumer friendly technologies which would certainly improve the operational as well as power quality issues associated therein.

Lastly, Government and Utility Involvement are very essential to meet the right Investment and quality Man Power Requirements that are essential for all the options to bring in a successful Smart Distribution Network leading to a smart National Grid.

For example, power theft issue discussed in Section IV "B" can be addressed through proper regulations and control on the load control switches and Data Management Services of smart meters and this has been marked accordingly through the indicative assessment table. Some of the Socio-Economic Challenges like the high capital investments Section III (a) above can be addressed through options like Time of Use Tariff Regulation and smart meter features which can energy audit, enhanced billing and increased revenue realization.

In the next section, integration of renewables has been considered as a case study. Solar PV is the technology chosen for the awareness survey of the Pondicherry SG pilot project. It has an impact on all the requirements mentioned in the indicative assessment table and this is the basis for its selection for the case study.

6. Case study: solar PV awareness survey in area of SG pilot project Puducherry

The potential for solar power generation is enormous in India, which is strategically located near the Equator in the so-called solar belt that exposes the Indian land mass to sunshine equivalent to 5000 trillion kWh of energy. The World Bank estimates India's renewable energy potential at over 150 GW (Sargsyan et al., 2011). Table 1 provides a snapshot of the solar opportunity for India:

Table 1
Calculation of solar potential in India (Ansari et al., 2013).

Land area of India	3,287,590 sq. km
Approximate number of sunny days	200
Unit potential of solar power from 1 sq. m	4 kWh/day
If conversion efficiency of solar PV cells	15%
Potential units of solar power from 1 sq. km	120 million units per year
If 0.5% of land is used for solar power installations	16,438 sq. km
Potential units of solar power from 0.5% of land	1972 billion units per year

Table 2
Respondent's demographic data.

Sr. no.	Description	Response	Response	Response
5	Monthly income in INR	(<15 k) 6	(15–50 k) 9	(>50 k) 6
6	Estimated monthly power consumption units in kWh	(0–250) 5	(251–800) 18	(>800) 2
8	Using star rated energy efficient appliances	(None) 2	(Some-most) 22	(All) 1

In India, as elsewhere in the world, the push to modernize the electricity infrastructure (the "grid") to make it more resilient and environmentally friendly has been a major source of inspiration for green thinking, and solar power has figured prominently in plans for diversifying distributed generation. India's ambitious Smart Grid Vision and Roadmap, announced by the Ministry of Power in 2013, envisaged policies mandating roof top solar PV installations for large footprint establishments, i.e., those with a connected load of more than 20 kW or "otherwise defined threshold" (MoP, 2013b). Reinforcing while also simultaneously amplifying the spatial scope of this "green" thinking, India's MNRE (Ministry of New & Renewable Energy) "Grid Connected SPV Rooftop, Solar Cities and Green Buildings Division" program represents an attempt to fast-track development of 60 towns/cities (designated Solar Cities), with at least one in every state, with financial support from the MNRE (GoI, 2014).

Against this backdrop, the survey report results from a demand-side study of home owners' attitudes toward, interest in and knowledge of rooftop solar in the city of Puducherry in the Union Territory of Pondicherry. Puducherry has been the site of a successful MoP Smart Grid pilot designed and implemented by PGCIL in collaboration with the PED. Puducherry falls under the purview of the MNRE's ambitious Solar City program. For the preliminary study, survey was done for 25 predominantly private, independent home-owners residing in areas covered by the PGCIL-PED Smart Grid pilot.

Puducherry falls under a low wind zone which is not suitable for wind generation while all other renewable resources, except solar are under conceptual/experimental stages only. However, Puducherry has solar insolation annual Average of 5.14 (kWh/m^2/day) which is very good and suitable for solar power generation. So, the Roof Top Solar PV system is promoted by Government Agency, REAP at Puducherry for domestic consumers to utilize the general land scape which is tropical and the usual good sunshine during most part of the year. In view of above, other renewable systems are not included in this study.

Puducherry SG pilot project has been implemented in Division-1 of PED and incorporates multiple technologies including rooftop solar PV. To analyze awareness of people about rooftop solar PV and their attitude toward this component of smart distribution network, on a small scale, consumer survey has been conducted.

Survey contains a convenient sample of 25 consumers of PED. Demographic data of respondent is as shown presented in Table 2. Respondent sample contains representation from each sector of society. Out of 25 respondents 6 have income less than ₹ 15k per month while 9 belongs to range from ₹ 15k to 50k per month and remaining 6 have monthly income more than ₹ 50k. On the basis of monthly energy consumption (in units of kWh), 5 respondents belong to that sector of society that consumes less than 250 units in month. Monthly consumption of 18 respondents is between 251 and 800 units per month while rest of the respondents consumes more than 800 units per month. Regarding knowledge of

Table 3
Respondent's house details.

Sr. no.	Description	Response	Response	Response
16	House details	(Own) 24	(Rented) 1	(Leased) 0
17	House type	(Independent) 14	(Small/large apartment buildings) 11	(Govt./society owned) 0
18	Availability of roof top space	(Available) 22	(Partly/not available) 2	(Not shadow free) 1

Table 4
Respondent's concerns/interest.

Sr. no.	Description	Response	Response	Response
7	Regularly used household appliances	(Computer/TV/fridge) 24	(Kitchen mixer/grinder/ geyser/water heater) 12	(Air conditioner/air cooler) 22
9	Type of electric bulb used	(Incandescent) 2	(Fluorescent) 8	(CFL/LED) 25
10	How often you review the monthly electricity bill?	(Never) 3	(Once/few) 17	(Very often) 5
11	How many times in a month do you experience power cut?	(5–10) 19	(11–15) 1	(>15/Daily) 4
12	When you have a problem with electricity service, you call	(PED) 22	(Neighbors/local resident association) 3	(MLA or political/prominent personalities) 2
13	Interested in energy saving/conservation measures	(Yes) 25	(No) 0	(May be) 0
14	Interested in Solar Power Generation other than Roof Top	(Yes) 21	(No) 2	(May be) 2
15	Whom you think RTS adoption would benefit	(Consumer) 24	(MoP/MNRE/GoI) 18	(PED/REAP/GoP) 9

energy efficiency, it is found that only 2 consumers out of the 25 are not aware and not using about energy efficient appliances, while rest are aware, concerned and using energy efficient appliances.

Table 3 gives an overview of physical details of respondent's house. Out of 25 respondents, one is living in rented home and 24 have their own house. Number of respondents living in apartment are 11 while 14 have independent type of houses. From space availability of rooftop perspective, 22 houses are available for roof top solar installation, 2 are partially available and one is not suitable for the same as it is not shadow free.

In survey, respondents were asked many questions among which few questions had "tick all that applicable" choice. Some of such questions and their response are presented in Table 4, which contains questions of respondent concerns and/or interests. Survey results shows that, except for one, all respondents are using appliances like computer, TV, fridge. 12 respondents are having appliances like kitchen mixer, grinder, and geyser and almost all except 3 respondents are having either an air cooler or air conditioner or both at their homes. It seems like all consumers in Puducherry are opting for energy efficiency as all 25 respondents says that they are using CFL/LED for lighting purpose. Only 2 respondents are still using incandescent bulb and 8 are having fluorescent lights. In response of question about their interest in energy saving/conservation measures, all 25 respondents said 'yes'. Respondents are well concerned about their electricity bills and 5 respondents said that they review their monthly bill very often, while others do the same once or few times in a month. On questions regarding power cut, 19 respondents said they have been experiencing 5–10 power cuts per month and 4 said they have been experiencing power cut on daily basis in their area. Besides so much power cut, residents have faith in PED and 22 respondents said they call PED when they experience any problem

Table 5
Respondents awareness and attitude toward rooftop solar PV.

Sr. no.	Description	Response	Response	Response
19	Would you like to use roof top space of your house for solar power generation?	(Yes) 21	(No) 0	(May be) 4
20	How did you find out about solar power?	(REAP) 0	(PED) 1	(Other) 21
21	Do you require funding assistance of 70% through a bank loan	(Yes) 6	(No) 12	(May be) 3
22	Do you wish to avail 15% subsidy from MNRE	(Yes) 17	(No) 2	(May be) 3
23	Do you prefer to have a battery backup	(Yes) 8	(No) 12	(May be) 1
24	For roof top solar, interested in	(Net metering) 14	(Feed in tariff with subsidy) 4	Net banking/adjustment 2

in electricity service. In response of question, if they are interested in solar power generation other than roof top, 21 respondents said ‘yes’ and 2 said ‘may be’ while 2 respondents said that they are not interested in any other solar power generation. Respondents believe that RTS (roof top solar) adaptation would benefit consumers, few also conveyed that along with consumers, Solar power adaption would be beneficial for either MNRE/MoP/GoI or PED/REAP/GoP or both.

Table 5 gives idea on consumer’s attitude and awareness about roof top PV solar. Respondents were asked would they like to use roof top space of their houses for solar power generation and no one said ‘no’. 21 respondents said ‘yes’ and rest 4 said ‘may be’. On asking about 70% funding assistance through banks, only 6 respondents said yes, 12 respondents said that they need no assistance while 3 said ‘may be’. Surprisingly, few consumers are not even interested in subsidy for same. On inquiring on their wish to avail 15% subsidy from MNRE only 17 respondents replied in affirmative. 2 respondents said, they do not need subsidy and 3 said ‘may be’. On the question of battery backup 8 respondents said they would prefer it, while 12 said they would not prefer battery backup. Despite of so many awareness programs from MNRE, MoP and PED it is surprising to notice that no one has mentioned Govt. programs as their source of information about solar PV. Only one respondent had mentioned PED and 21 have said that they came to know about roof top solar PV from other sources.

Survey analysis shows that, consumers have basic awareness about solar PV, which is a major component of smart distribution network. Since, till now consumer awareness programs from Govt. agencies are not much successful and hence need to be addressed more aggressively. Experience from survey of roof top solar, could be useful for other SG technologies also. Consumers are willing to accept technologies for efficient and improved services which is evident from the faith they showcased on PED.

The PV installations are made by standard vendors listed by the MNRE and it is integrated to the existing utility network through a current controlled voltage source inverter. The conventional energy meters are replaced by smart energy meters having net metering facility. Hence the consumer did not require any technical expertise in operating a Solar Roof Top PV system. Hence, consumer awareness about the benefits of RTS rather than the technical aspects of RTS is brought out in the survey.

7. Conclusion

Across the globe, utilities are attempting to transform age old power grids into smart distributed power systems with great efforts to resolve the challenges that arise on the way. Major challenges in SG technology are renewable integration, data management, stability, cyber security etc. Although there is no final solution found, multiple approaches from researches are under trial/implementation through several pilot projects. Socio-economic issues are prevailing but being resolved through joint efforts. Governments and organizations are sharing the high capital investment involved in these pilots and ensuring support and confidence to all stake holders. Awareness programs are set across various platforms to bring a higher understanding and cooperation. Other issues viz. privacy, regulations, policies, power theft and many other problems are being identified and resolved. An indicative assessment framework has been developed and details are discussed.

Several agencies are also working as a feedback network; they are analyzing the efforts to make SG a nearby success to reap its benefits. Reduced cost, enhanced reliability, improved power management, self-healing grid infrastructure, new jobs, satisfied consumer, green and clean power etc. are the major impacts that encourage SG and its global expansion. Despite several issues, consumers are willing to adopt smart distribution network. They are concerned and do have supporting role with utilities and government also which is well revealed from the successful mini pilots SG project implemented at PED, Puducherry, India

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