Smart Grid Working Opportunities and Challanges in India – A Review

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***Abstract* —India's power area is experiencing a sturdy boom in demand, manufacturing, and energy transmission. India is operating on several progressive policies and programs within the energy sector for holistic transformation. A facts-driven smart utility released by India will soon open up new commercial enterprise possibilities. Rapid populace growth and urbanization have a prime effect on energy consumption and power generation. Moreover, energy control is the largest task and an essential part of all kinds of regions. The Smart Grid performs a crucial role in this due to its benefits like contributing to the discount of T&D losses, Peak Load Management (PLM), progressing Quality of Service (QoS), improved reliability, better asset control, renewable integration, and better accessibility to electricity. National Smart Grid Mission (NSGM) was launched by the Ministry of Power (MoP) to deal with key problems of Smart Grid tasks on a large scale in the country and to make the Indian power infrastructure cost-effective. This paper first briefly describes the overview and making plans of the Indian energy sector followed by the development of pilot projects of Smart Grids in India and proposed several working opportunities in India towards Smart Grid. Challenges and barriers related to smart grid is also proposed in this paper.**

Keywords—smart city, smart grid, energy management system, national smart grid mission, smart grid task force, indian smart grid forum

I. INTRODUCTION

The Indian energy sector marketplace is laid low with a high strength shortage in a developing economic system in which the strong demand is increasing each day. The power region of India at present faces many demanding situations to meet the increasing call for-supply standards. As in keeping with the information from the Ministry of Power (MoP), electricity losses in India's transmission and distribution sector exceed 30% of the general era, which is one of the maxima in the global. To triumph over those troubles in the Indian energy area advancing the grid infrastructure throughout all its segments is needed to reduce the related losses. This development in an electric-powered grid is viable via Smart Grid technology. The Ministry of Power with inputs from the India Smart Grid Forum (ISGF) and India Smart Grid Task Force (ISGTF) issued a Smart Grid imaginative and prescient Roadmap for India in August 2013. Smart Grid's vision for India is to "*Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with the active participation of stakeholders*" [1].

A Smart Grid is an electrical Grid with Automation, communication, and IT systems that could monitor the power flows from points of an era to points of consumption and manage the power drift or curtail the weight to suit generation in real-time [2]. The Government of India (GoI) has been growing numerous guidelines and packages to guide the mainstreaming of Smart Energy Management (SEM) into urban planning. The National Electricity Policy (NEP) and NITI Aayog focus on energy get right of entry to for all, lowering dependence on fossil-fuel imports, selling low-carbon improvement, and sustainable financial increase [3].

A shortage in the generation or consumption of power may disturb the network and create severe problems. To increase the balance between supply and demand in an efficient way, and to reduce the peak load energy management systems are utilized. Energy management systems can be divided into two categories, one is on the side of the supplier also called a Supply Side Energy Management (SSEM) and the other is on the consumer side called Demand Side Energy Management (DSEM). Demand-based strategies are relevant to integrating power control for sustainable smart cities were proposed beneath the NEP for the transport, buildings, and family quarter.

II. ENERGY SECTOR IN INDIA

One of the most crucial components of infrastructure, power is necessary for both economic growth and the welfare of the country. There needs to be enough electrical infrastructure constructed in order for the Indian economy to flourish steadily. India generates its power from a variety of non-conventional sources, including wind, solar, and waste from homes and farms, as well as conventional sources including coal, lignite, natural gas, oil, hydropower, and nuclear power.

The Indian electricity sector is going through a major transformation that has changed the outlook for the sector. India's need for power is still being driven by steady economic expansion.

A. Power Scenario Overview

The Indian government's emphasis on achieving "Power for all" has sped up capacity expansion across the nation. Since independence, power generation has increased more than 100 times; yet, because of rising economic activity, consumption has climbed even faster.

As of July 31, 2023, India ranked third in the world both in terms of electricity production and consumption, with an installed power capacity of 423.25 GW as shown in figure 1. India had 177.73 GW of installed renewable energy capacity (including hydro) as of July 31, 2023, accounting for 41.9% of the country's total installed power capacity. As of July 31, 2023, the largest contributor to energy was solar power with 71.14 GW, followed by wind power with 43.94 GW, biomass

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with 10.24 GW, small hydropower with 4.98 GW, waste to energy with 0.57 GW, and hydropower with 46.85 GW.

India's energy companies have advanced significantly in the world energy market. Oil and Natural Gas Corp. Ltd. was placed 14th in the S&P Global Platts Top 250 Global Energy Rankings 2022 [4].

At US$ 90 billion, India came in sixth place among nations that made large investments in sustainable energy between 2010 and the second half of 2019. Between April 2000 and March 2023, FDI inflows into the power industry totaled US$ 16.58 billion, or 2.61% of all FDI inflows into India. Between FY19 and FY23, investments totaling US$ 128.24–135.37 billion (around Rs. 9–9.5 trillion) are expected to flow into India's electricity sector. Projects in the energy sector accounted for the largest portion (24%) of the US$ 1.4 trillion (Rs. 111 lakh crore) total estimated capital expenditure, according to the National Infrastructure Pipeline 2019–25.

In the fiscal years FY21, FY22, and FY23, India generated 1,373.08 BU, 1,484.36 BU, and 1,617.72 BU of energy from renewable and non-renewable sources, respectively. Programs like the Integrated Power Development Scheme (IPDS), Ujwal DISCOM Assurance Yojana (UDAY), and Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY) are helping to increase electrification across the nation. In order to speed up clean energy innovation, India has also started the Mission Innovation CleanTech Exchange, a worldwide project that would build an entire network of incubators among its member nations.

With investments made across the value chain, India is poised to become a worldwide hub for manufacturing. According to the Central Electricity Authority (CEA), India's electricity needs would increase to 817 GW by 2030. By 2030, the government wants to have 500 GW of renewable energy installed. The government of India has shown its keen hobby in the development of the Smart Grid system and therefore it incorporates a large budget for this.

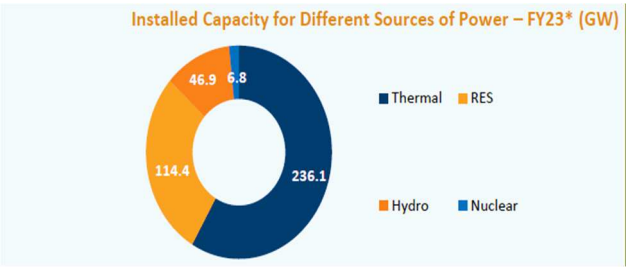

Fig. 1. Total installed power capacity

B. Smart Grid Development in India

Renewable energy sources are very variable and sporadic in nature, in contrast to traditional energy sources. In order to ensure grid stability and security, large-scale integration of renewable energy requires specialized balancing mechanisms to deal with uncertainty and fluctuation. The development of microgrids is also necessary to support capacity augmentation and distant area electricity. For such large-scale RE integration to be successfully integrated, all relevant parties—government agencies, non-governmental organizations, manufacturers, R&D centers, financial institutions, developers, and, of course, a new generation of energy entrepreneurs—would need to actively participate [5].

It is imperative that all stakeholders actively participate in the smooth integration of emerging technologies in the areas of IT systems, communication, automation, control, and monitoring in order to address these problems and improve efficiency. In this sense, the smart grid, which combines technology from the twenty-first century with the electrical infrastructure from the twentieth, has the ability to transform the energy delivery system and guarantee that everyone has access to electricity.

The power sector has immense boom opportunities and is predicted to develop exponentially within the next 5 years [6]. Indian Smart Grid task force (ISGTF) beneath MoP, GoI has shortlisted 11 Smart Grid pilot projects as shown in figure 2 [7], spread throughout the country for demonstration of the technology.

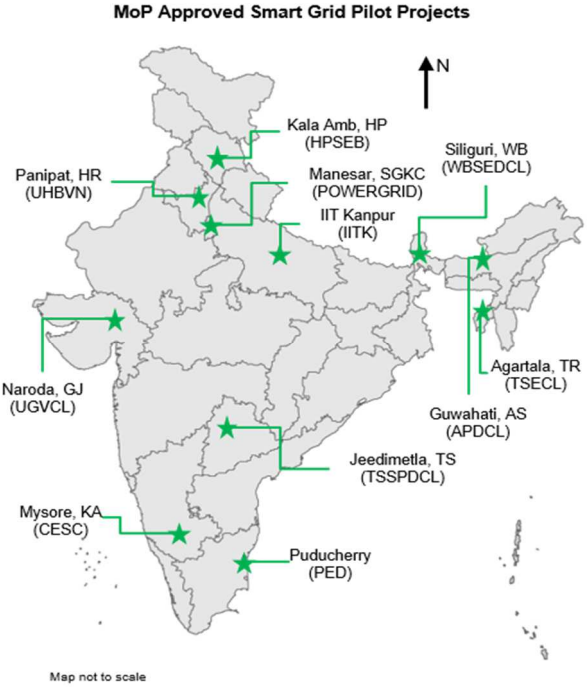

Fig. 2. Smart Grid pilot projects in India

C. Status of Distributed Sectors in India

The Indian electricity system's distribution sector experiences operational inefficiencies (high AT&C losses, frequent and protracted outages, etc.). In 2011–12, the average AT&C loss for utilities that sell directly to customers was 27%. India now has average AT&C losses of 13.5 percent, a significant decrease as shown in figure 3. Given that a decrease of almost 8.8 percentage points has been accomplished in just two years, this is a significant accomplishment, according to Ministry of Power Secretary Alok Kumar. There are other factors to be concerned about, such as power quality and supply reliability. The success of the whole electricity industry depends on the distribution sector's state of health. Most consumers are passive, meaning they seldom engage in energy management and have little awareness of their consumption habits.

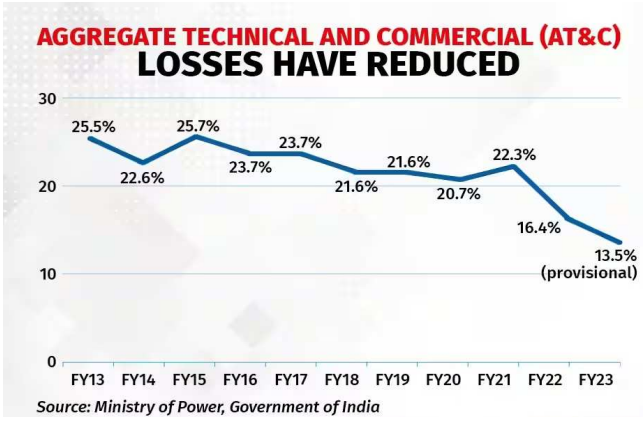

Fig. 3. Average AT&C losses

III. Smart Energy Management Opportunities and Challenges in India

The Smart Grid will make it easier for electricity to flow both ways by enabling real-time interaction and condition reaction. Large-scale, potentially capital-intensive infrastructure upgrades in the areas of field systems, IT programs, smart devices, communication networks, and other areas may be necessary for this. The primary to principal policy-level adjustments in the energy sector are related to essential generating modifications, outdated infrastructure, and sporadic efficiency. Technological developments in the distributed era and storage, electric cars, communication, and automation are opening up new investment and value-generating opportunities.

Shortages in supply, large T&D losses, power theft, and inefficient metering and revenue collection are among the issues affecting India's power sector. India has the highest transmission and distribution losses in the world, accounting for 26% of the country's total energy production on average. When energy theft is taken into consideration, overall losses can reach 50%.

The aforementioned changes are creating new avenues for the bidirectional flow of information and energy, enabling customers to have an active role in the entire supply chain. In order to build reliable and intelligent grids, developing countries like India must invest in improving the electrical grid in addition to communications, IT, and automation systems. The new utility enterprise models are listed below [8].

A. Benefit Sharing Model

All of the central government-funded programs to reduce AT&C losses benefited from technological interventions that made it easier to pinpoint the sources and locations of losses and enabled distribution companies (DISCOMS) to implement the appropriate technical and managerial countermeasures. The Indian government's Ministry of Power released the Smart Grid Vision and Roadmap for India in 2013, aiming to convert the entire Indian power system to Smarter Grids by 2027 [9]. The following are some benefits that could result from the adoption of Smart Grid initiatives:

- Lower AT&C losses
- Lower equipment failure rates
- Lower power purchase costs
- Lower network upgrade costs as a result of peak load

Developing business models for smart cities is challenging, and proving a return on investment is even more so [10]. Benefit-sharing models, however, offer a viable option for the business case for smart grids. Once the infrastructure for smart grids is established, it may be very inexpensive to expand its use to include new services and domains in order to build smarter cities.

B. Rollout Strategy for AMI

Given the substantial capital expenditures necessary to deploy hundreds of thousands of smart meters and the current state of DISCOMS' finances, the following AMI rollout on "Leasing" and "Service Version" is suggested:

- Meter procurement on a leasing model
- AMI implementation and maintenance on the service model
- Rollout philosophy

A greater understanding of the challenging circumstances and implementation barriers of smart energy management is made possible by the executive, coverage, financial system, generation, socio-environment, and legal evaluation highlighted in Table 1 [11].

Typically, variables including vehicle efficiency, usage and distance traveled, fuel and energy kinds, and overall system efficiency of transport infrastructure determine the energy consumption and carbon emissions of the transportation sector [13].

TABLE I. Smart Energy Management (SEM) Challenges in India

Area	Challenges
Executive	Special sectors' portfolios are not aligned, and one of the main problems continues to be partners' inadequate cooperation and lack of attraction. There are little tools available for information dissemination and little public participation.
Coverage	India lacks comprehensive, long-term planning and laws for efficient energy management. Regardless, or perhaps as a result of conflicting policies and intricate planning for urban administration, SEM governance in India continues to be disjointed and devoid of sustained political commitment and support.
Finincial System	The large-scale utility of SEM solutions is hampered by obstacles such as restricted access to finance, poor external economic assistance for projects combined with the financial crisis, risks, uncertainties around new technology, and exorbitant costs for goods and substances.
Generation	Examples, procurement organizations, verified and vetted responses, and personnel with the necessary training and experience are lacking. Because the field is new, full of dangers and planning flaws, industry involvement in SEM projects is limited, voluntary, and lacks strong effects.
Socio-Environment	Most SEM moves in India are hoped to be supported by government-led initiatives, as well as demonstration and pilot projects. Negative results from SEM-related project interventions in the natural and social environments may also make people less interested and inert.
Legal	There are not enough strong, pro-business regulations or financial incentives to support innovative, cutting-edge technology. One of the biggest obstacles to technology standardization is the lack of consistent laws.

C. Discussion and Recommendations

The design and technology of smart grids necessitate that energy system planning depart from the conventional wisdom on energy storage and adopt a more sustainable and effective framework. Establishing energy storage as a new asset class and providing an appropriate set of financial and regulatory regulations to promote its development are necessary to fully realize the benefits of smart grid and storage technologies. There is a renewed push in India to adopt DSM widely in order to solve the challenges of climate change and global warming.

Table 2 summarizes the most important smart energy management strategies across industries for the issues that have been raised.

The Indian government, or GoI, has been formulating policies and initiatives to direct the integration of SEM into urban planning. Table 3 summarizes the SEM policies governance in India [13]. In India, local governments are integrating smart energy techniques into public services. Examples of current or planned projects include district regional cooling systems, smart grids, smart metering, net metering, and renewable energy integration. However, there are barriers to the widespread implementation of publicly available service-based SEM technologies, including insufficient guidelines, standards, and business models, as well as ineffective federal, state, and local legislation and regulations. Policies and programs that educate stakeholders and the general public about the advantages of SEM should be put into place first.

TABLE II. A SUMMARY OF KEY SMART ENERGY MANAGEMENT (SEM) SOLUTIONS IN DIFFERENT SECTORS

Sector	Solutions
Building	• Linkage with the smart grid • Enhance the air conditioning • Enhance lightening systems and controls • Enhance recovery of heat & storage system • Hybrid ventilation system • Solar-powered active ingredient • Incredibly efficient generators • Flexible façade system
Water	• Real-time monitoring and data collection • Intelligent metering • Leak detection • Integration of power, control, and security systems • Effective pumping mechanism • Facilities for treating and reusing water • Management of urban flooding and storm water • Operational system integration
Transport	• Enhance transportation mechanism • Enhance public transportation • Integrated mobility, multiomodel & shared transport • Infrastructure for EV charging and oversight services • System of intelligent traffic management • Congestion charges and tolling
Waste	• Enhance monitoring of general waste • Integration of solar • Recovery of industrial heat • Biological & advanced thermal treatment • Waste-to-energy conversion • Intelligent recycling facilities • Intelligent waste bins • Dynamic management and routing
Public Services	• Intelligent sensors • People safety • Visual surveillance • Digital city services • People street lightening mechanism • Intelligent district heating & cooling • Automated distributed control system • Renewable and seperated energy generators • Electrical & thermal energy storage

Some of the suggested measures are listed as follows:

- Governments can use a variety of fiscal incentives, grants or subsidies, financing availability, tax exemptions, and product refunds to encourage participation from business, industry, and civil society.
- Encourage the use of printed materials, online resources, websites, online competitions, national campaigns, conferences, events, and media campaigns.
- Involve businesses, industry "champions," developers, planners, architects, real estate companies, transportation networks, energy consultants, and energy managers in outreach initiatives and projects.
- Provide thorough manuals, encyclopedias, databases, and guides that compile national and international best practices, examples, approaches, technological solutions, and current policies, initiatives, and programs.

TABLE III. SEM POLICIES OF INDIA

Year	SEM Policy
2001	The Energy Conservation Act
2010	National Mission on Enhanced Energy Effiency [14]
2010	National Mission for Sustainable Habitat
2010	National Solar Mission
2015	Smart Cities Mission
2017	Draft National Energy Policy
2018	Draft National Cooling Action Plan

IV. SMART GRID WORKING OPPORTUNITIES IN INDIA

India's economy is expanding rapidly as a result of the rapidly expanding power sector. The best working chances are provided by smart grid. The suggested employment prospects in the context of the Indian market [12] are as follows:

A. Generation Domain of Smart Grid

- The coexistence of several energy producing technologies necessitates coordination in order to guarantee secure and stable system operation.
- It is necessary to advance a number of communication technologies, including as Wide Area Management Systems (WAMS), which regulate the functioning of generating stations.
- Potential for enhancing the infrastructure for communication.

B. Transmission Domain of Smart Grid

- Communication interface networks can be developed because it is important to transfer power from transmission networks to power distribution systems with the least amount of energy loss possible.
- Real-time transmission network monitoring is required, as is safeguarding against any potential disruptions.

- Controlling the power flow and voltage on the lines is necessary to keep the operation steady and secure.

C. *Distribution Domain of Smart Grid*

- The two most important factors for smart distribution systems will be distribution and substation automation. Thus, optimizing the utilization of Distributed Energy Resources (DERs) will yield optimal outcomes for distribution networks.
- Since system operators typically operate from a distance, there are excellent chances to build the communication infrastructure necessary for information sharing between central distribution systems and substations.

D. *Customers Domain of Smart Grid*

- Through demand response, users (residential, commercial, and industrial) are integral to the Smart Grid.
- There is a need for intelligent systems like IoT, AI for peak-load shaving, valley filling, real time pricing, etc.
- Networks of seamless communication between users and system operators are seen as opportunities.

E. *Operations Domain of Smart Grid*

- The operating component of the smart grid includes smart metering, recording, and controlling activities; therefore, real-time information exchange with the energy market needs to be developed.
- Demand management systems provide the greatest working conditions since they play a significant role in the information flow between consumers and operators.

F. *Markets Domain of Smart Grid*

- With Indian Smart Grid's vision and objective, the market for smart grids has a lot of room to grow.
- Therefore, it is necessary to develop a number of suitable regulatory policies to ensure the seamless integration of the various Smart Grid sectors.

G. *Service Provider's Domain of Smart Grid*

- As the Smart Grid business model develops, that area of the technology changes.
- In order to create favorable chances, service providers must have an appropriate interface for communication with operators, marketplaces, and consumers.
- A few of the services include energy forecasting, account management, building and home management, installation and commissioning services, and billing administration.
- In addition, there are positions available in the fields of electromobility, grid modernization, and cyber security, and predictive maintenance, process sensing, grid interconnection, area sales, system analysis, and power sector consulting.

V. Conclusion

India's urban population is expected to increase significantly over the next several decades, which might have a significant impact on energy consumption and demand. Combining clever energy management techniques from several sectors is necessary to reduce carbon emissions and turn India's metropolitan areas into sufficient, energy-efficient cities.

A smart grid could serve as a foundation for smart cities, accelerating the creation of livable, practical, and sustainable urban environments. In order to build a sustainable future and permit the use of green energy in smart cities, renewable electricity is essential. Better planning and an understanding of the interdependencies of different domain names may be facilitated by a well-known framework for smart cities.

The aforementioned employment prospects highlight India's strong growth prospects in the electricity sector and the vast research opportunities in the context of India's smart grid.

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