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Smart Grids, Micro Grids, Virtual Power Plants and Their Future Applications in India

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Abstract—*Recent technical and digital advances have put India on the cusp of a massive energy generation, distribution, and consumption change. Just as the slow-moving, polluting modes of public transport on Indian roads are rapidly giving way to the faster, cleaner Metro Rail networks, India's energy sector, too, is trying to break the shackles of legacy systems.*

Power generation companies in India use multiple technologies to produce electricity through varied sources such as Thermal, Hydro, Solar, and Nuclear. To meet future demand effectively, India is evaluating advances in Smart Grid technologies for power management.

This paper begins by defining a Smart Grid and its technical architecture. It then explains Micro grids and their hierarchical control structure for drawing and managing power. Third, a Virtual Power Plant and its technological building blocks are defined.

The research then discusses developments in India in technology studies, pilot testing, technical standardization, and design infrastructure necessary for the future adoption of Smart technologies in electricity management. The paper highlights many simultaneous changes to systems and platforms that will need to be implemented for the shift to integrated energy systems to become a reality in the future.

The paper concludes with two case studies showing the application of Smart Grids in India that promise to deliver tangible benefits of lower electricity costs and increased productivity to meet the growing demand by making available energy from multiple sources efficient and green. These technologies hold the potential to transform India's power industry in the coming decade or more. And like all technological leaps, this will also have its share of challenges as engineering capabilities, and commercial viability converge.

Smart Grids, Micro grids, Virtual Power Plants (VPP), and Their Applications in India

India has the world's 2nd largest synchronous grid and the 3rd most extensive **power consumer base**[i] with an installed capacity of 384 GW as of July 2021,[ii] covering three million sq. km in a country of 1.4 billion people. And yet, 240 million[iii] of them still do not have access to electricity. As demand rises, India's installed capacity is estimated to go up to 1,420 GW[iv] in the next 20 years, akin to adding the European Union's total installed capacity as of 2018.[v] As India's GDP grows at a 5% growth rate from 2020 to 2030, power demand would increase 1.6 times, which would still be only 50% of the current global mean.[vi]

India's energy mix of Thermal, Renewable, Hydro and Nuclear power constitutes 61.5%, 25%, 12.2%, and 1.8% of the total capacity, respectively[vii]. Electricity generation, distribution and transmission are primarily owned by government entities that also formulate relevant policies. The Government plans to meet the country's electricity demand through the National Grid in a distributed generation mode, which focuses on producing energy closer to consumption. It envisages a versatile system that incorporates both renewable and fossil fuels. In this context, this paper looks at efficient methods such as Smart Grids, Micro grids and Virtual Power Plants (VPP) and analyses the developments underway in India.

Can Smart & Micro grids, Virtual Power Plants Transform Electricity Management?

Smart Grids: Electricity from a power plant is delivered by a network of transmission lines, substations, transformers and more. This paper details the technological advancements that could potentially manage electricity from several sources, meet the requirements of different consumers, track usage patterns by analysing big data, integrate multiple systems, harness green power and meet complex electricity needs.

Smart Grid engineers are evaluating, building and automating systems of power generation, transmission and usage. Moreover, the new equipment and designs will come about, and power plants will need to talk to transmission lines, balance power demands nationwide, and minimise wastage and downtime. Experts say the transformation in India's power sector will be akin to how the Internet transformed living.[viii]

A Smart Grid's ability to provide flexible electricity flow can help balance supply and demand, curbing power outages and malfunctions[ix], making it superior to traditional power grids. Micro grids and VPPs are subsets of a Smart Grid and work well alongside. The following section provides their definitions, along with examples of their applications.

Micro grids: Meeting Local Power Needs

Micro grids are emerging as game changers because of their numerous advantages over traditional grids. They are localised units that can operate autonomously when the primary grid is down, strengthening grid resilience. The use of local energy sources for local loads can help cut transmission and distribution losses. On the demand side, too, Micro grids can control sudden surges or drops in power usage. Micro grids are limited by geography and the scale of Power Systems, even though they can integrate with distributed grids. Virtual Power Plants, as a concept, were developed to overcome such limitations.[x]

Virtual Power Plants

Because of its simple concept, a Virtual Power Plant (VPP) is an excellent alternative to a conventional transmission-based power plant.[xi]Virtual Power Plants can integrate different electricity generation resources and distribution units on a single operating platform, thereby eliminating the barriers of traditional power plants. India is a large country with remote and challenging terrain, where several towns and villages lack National Grid connectivity. In such regions, VPPs can help transform the quality of life, as the networks use local distributed energy resources (solar, wind, hydropower, or biomass) to optimise generation and consumption.

India Needs Smart Solutions for its Growing Power Demand

The latest Economic Survey of India highlights that Transmission and Distribution (T&D) losses at 20.6% as of October 2020 are twice the world average,[xii]and Aggregate Technical & Commercial (AT&C) losses are very high and vary widely, from 6% to 60%.[xiii] Recognising these challenges, India has set the following targets: Reducing AT&C losses to 12%-15% by 2024-25[xiv], creation of efficient, viable, and technologically sound power distribution companies, and deployment of Smart Meters to improve efficiency in the power sector.

Smart Meters provide real-time data of end-users, and when connected to a Smart Grid, they contribute to higher efficiency. Smart Meters offer accurate readings, remote billing of net-energy consumed, and managing electricity connections. Once implemented, they will gain importance.[xv]

For Smart Grids to become commercially available in the future, public-private partnerships[xvi] are necessary for their adoption. Some of the initiatives are:

i. Roll out of 250 million prepaid Smart Meters, 100 million by 2023 in urban centres.[xvii]
ii. Narrow-Down Meter Technology.
iii. Financial Support to strengthen state distribution companies.
iv. Feeder segregation for agriculture and non-agriculture electricity consumers, to bill them differentially.
v. Modern distribution systems in 100 urban centres for higher efficiency.
vi. Roll out of Smart Meters to lower AT&C losses and evolve appropriate tariff.
vii. FAME INDIA: Incentives to manufacturers of hybrid or electric vehicles and rollout of charging infrastructure to build demand for EVs.[xviii]

Manifold Benefits of Smart Meters in India

Smart Metering can provide manifold benefits for India's electricity ecosystem. Pilot studies have shown distribution companies can cut power losses and theft, measure electricity usage precisely, make pricing dynamic, and provide net metering solutions. Global experience shows that Smart Grids can connect with data sources such as water and gas meters, making them an anchor infrastructure for India's goal of 100 Smart Cities by 2023.[xix] Unlike traditional grids,[xx] they can help Smart Cities with efficient distribution, managing fluctuations, and balancing demand and supply. With this in mind, Indian government entities are taking policy steps and conducting technical pilots to introduce Smart Grids.

Smart Grid Initiative in its Infancy in India

The Indian Government aims to transform its electricity sector into a digitally-enabled ecosystem. Already, India has taken several steps for the rollout of Smart Grids: Launch of the National Smart Grid Mission in 2015; release of Smart Meter and Advanced Metering Infrastructure specifications; Smart Meter installation targets by distribution companies (DISCOMS) under the Ujwal DISCOM Assurance Yojana (UDAY); and 12 Smart Grid pilot projects across India.

However, since these are evolving technologies, widespread global adoption will gather pace over the coming decades as research advances in this field. India's largest transmission company POWER GRID is playing a vital role in the rollout of Smart Grids over the next 10-20 years. A few initiatives by POWER GRID in areas of Smart transmission and e-mobility include implementing Wide Area Measurement systems nationally, adopting Electric Vehicles (EV) for their use, and installing fast-charging stations across India. POWER GRID will also assist government enterprises in installing EV charging stations at their retail outlets.[xxi]

In summary, these pilot projects provide several tangible benefits in rolling out Smart Grids in the future, balancing out between the existing infrastructure and new capital expenditures. There are opportunities for power utilities to vastly improve operational and financial efficiency, even when undertaken on a small scale.[xxii]

Discussion

India is doing all it can to light up the homes of every citizen, and it is not as if power is in short supply. The problems are manifold: Difficult and remote terrains, huge power losses on account of poor transmission and electricity theft, the baggage of outdated technology and distribution systems that make the country's energy sector a sluggish behemoth.

But all this is poised to change as the emergence of new technologies enable India to switch over to Smart digital systems and advances in engineering to meet its rising demand for electricity cost-effectively.

Modern digital technologies promise to make India's energy sector more efficient and profitable for all stakeholders – consumers, utilities, and the Government. Emerging concepts like Smart Meters, Smart Grids, Micro grids and Virtual Power Plants have the potential to significantly upscale production, transmission and distribution of electricity. India is pilot testing these technologies by incorporating them with its legacy infrastructure to transition to an energy ecosystem that is efficient, secure and environment friendly. As engineering capabilities and commercial viability converge, adoption and transformation will happen over the next decade.

Further, India's ambition to develop 100 Smart Cities will boost as global experience shows that Smart Grids can connect with different data sources such as water and gas meters and serve as an anchor infrastructure for Smart Cities. The National Smart Grid Mission set up in 2015 has rolled out 12 Smart Grid pilots across the country, while power transmission company POWER GRID is at the forefront of conducting pilot projects and standardising systems and practices for an eventual rollout of Smart Grids. India cannot completely discard its massive legacy power infrastructure. It will leverage intelligent innovations that can bridge the old with the new on common platforms that promise a win-win proposition for all stakeholders. India's energy future does look bright!

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