Microgrid: A Blueprint for Decentralized Energy Systems

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Abstract. India's push toward renewable integration and decentralized energy has made Microgrids, Mini grids, and Distributed Energy Resources (DERs) vital for energy access and sustainability. The government's PM-Surya Ghar scheme and policies from bodies like MNRE, CEA, and CERC promote DER adoption, particularly in rural and remote regions. State-specific regulations in Uttar Pradesh, Gujarat, and Rajasthan also support microgrid growth through financial incentives, simplified approvals, and innovative frameworks like blockchain-based energy transactions. Case studies, including the NTPC NETRA Microgrid Project and community initiatives in West Bengal and Jharkhand, underscore the adaptability and social impact of microgrids. Despite challenges in financial viability and regulatory alignment, enhanced subsidies, community engagement, and R&D investments can drive further deployment.

Keywords: Microgrid, Battery Energy Storage System (BESS), Distributed Energy Resources (DERs), Smart Grid, Energy Policy.

1. Introduction

Microgrids, mini-grids, and Distributed Energy Resources (DERs) are key concepts in decentralized power generation and distribution, aimed at enhancing energy access, reliability, and sustainability. This decentralized model promotes renewable energy integration, local energy independence, and resilience against power disruptions. Together, these technologies are essential for modernizing energy systems and achieving sustainable and reliable electricity access for all.

The Indian government has recently introduced a national framework to promote DERs. One of the government's schemes, PM-Surya Ghar: Muft Bijli Yojana, aims to provide 300 units of free electricity per month to one crore households through rooftop solar installations. The scheme is implemented through a structured framework involving both national and state-level agencies [1]

India's energy sector has undergone a significant transformation, driven by ambitious targets for renewable energy integration and the need to provide reliable electricity access across rural and remote areas. Microgrids and mini grids, defined by capacities below and above 10 kW respectively, have emerged as vital components in bridging the energy access gap. This research paper assesses the current policies,

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institutional roles, and deployment of microgrids in India, emphasizing the role of the Ministry of New and Renewable Energy (MNRE), Central Electricity Authority (CEA), Central Electricity Regulatory Commission (CERC), state-specific policies, and the broader impact on sustainable development.

2. Indian Institutional and Policy Framework

2.1 Ministry of Power (MoP)

The Office Memorandums issued by the Ministry of Power (MoP) India for the National Smart Grid Mission (NSGM) highlight financial support initiatives for microgrids., covering up to 30% of project costs as grants. Key requirements include adhering to technical standards for grid integration and maintaining power quality. The mission promotes rooftop PV systems within microgrids and mandates real-time monitoring for improved reliability. Additionally, consumer engagement and staff training are prioritized to build community support and operational expertise. Microgrids are encouraged in islands, SEZs, and remote areas where grid expansion is challenging, with careful site selection essential to ensure environmental and project benefits [2].

2.2 Ministry of New and Renewable Energy (MNRE)

The MNRE is the primary body responsible for India's renewable energy policy and has pioneered initiatives supporting microgrids and mini grids. In 2016, MNRE issued a Draft National Mini and Microgrid Policy aimed at deploying 10,000 renewable energy-based micro and mini-grids, targeting a capacity of 500 MW over five years. The policy emphasized financial support, technical standards, and operational models (including "open market" and "mixed" approaches) to encourage private investment and state-level policy adaptation [3].

2.3 Central Electricity Authority (CEA)

The CEA of India has not issued a dedicated policy exclusively for microgrids. However, microgrids are addressed within broader frameworks and guidelines concerning distributed generation and renewable energy integration.

The National Electricity Plan (NEP) Volume I (2023) and Volume II (2024) by the Central Electricity Authority (CEA) address India's strategy for integrating microgrids and renewable energy sources into its power infrastructure.

Volume I emphasize the role of microgrids in rural electrification and distributed power generation, recognizing challenges like high initial costs, technical complexities in grid integration, and cybersecurity risks. It highlights the need for regulatory support and financial models to ensure microgrid viability [4].

Volume II focuses on the transmission system, addressing the technical and infrastructural demands of integrating microgrids with the national grid. Key challenges include cybersecurity, transmission capacity needs, and regulatory alignment to facilitate microgrid operations [5].

Both volumes underscore the importance of technological advancements, such as hybrid substations and virtual power plants (VPPs), to enhance grid stability and resilience. The CEA emphasizes cybersecurity protocols, robust infrastructure, and streamlined regulations as critical to supporting decentralized energy solutions, especially for renewable energy integration.

The CEA Technical Standards for Connectivity of Distributed Generation Resources provides guidelines for safely integrating microgrids and other distributed generation resources into India's electricity grid. Key standards cover voltage, frequency, synchronization, and cybersecurity to ensure grid stability. These guidelines align with international benchmarks, notably the IEEE 1547 standard, to maintain consistency and uphold best practices in grid interconnection. Microgrids must have protection systems for fault detection and comply with power quality standards, including harmonics and voltage stability, as per IEEE 519-2014. Additionally, distributed generation resources require a Unique Registration Number and regular compliance checks. These standards are essential for maintaining reliable and secure grid operations while supporting the growth of decentralized energy sources like microgrids [6].

2.4 Central Electricity Regulatory Commission (CERC)

CERC's regulations support the integration of Distributed Energy Resources (DERs), including Renewable resources with storage, hybrid energy projects, into India's power system by establishing guidelines on grid connectivity, tariff determination, and market access. The Tariff Determination for Renewable Energy Regulations, 2020 ensures fair compensation, enhancing financial viability for microgrid projects. Grid Code and Connectivity Regulations outline standards for safe integration with the main grid. Power Market and Deviation Settlement Mechanisms enable DERs to participate in power markets and manage renewable variability. Renewable Energy Certificates (RECs) incentivize clean energy production, while ancillary services and storage guidelines further promote operational stability and flexibility for microgrids and Mini grids [7] [8].

2.5 State-Specific Policies

Some States of India have led the way in adapting central bodies framework into localized policies as follows:

Uttar Pradesh. introduced a mini-grid policy in 2016, offering a 30% subsidy to private players who operate under a Build, Own, Operate & Maintain (BOOM) model. The policy ensures power supply for a minimum of eight hours daily in underserved areas, contributing to job creation and local manufacturing [9].

Bihar and Odisha. included mini grids within broader renewable energy frameworks, offering incentives to developers and streamlining the approval process to encourage private sector involvement [10] [11].

Karnataka. The Karnataka Peer-to-Peer (P2P) Solar Energy Transaction Regulation enables secure, blockchain-based energy trading that aligns well with microgrid operations. By supporting local renewable integration, empowering participants as "prosumers," and providing real-time monitoring, this regulation promotes resilient, efficient energy exchanges within microgrids, enhancing community-based energy management and independence [12].

Rajasthan. The Rajasthan Electricity Regulatory Commission (RERC) Regulations and its amendments are designed to facilitate the integration of Distributed Energy Resources (DERs) into Rajasthan's power grid, with specific implications for the development and operation of microgrids and Mini grids. The RERC regulations support the deployment of DERs, by providing technical, financial, and operational guidelines. By simplifying approval processes, promoting net metering, enabling flexible tariff structures, and offering financial incentives, the regulations make it easier for microgrids to thrive in Rajasthan [13] [14] [15].

Gujarat. The Gujarat Electricity Regulatory Commission (GERC)'s Green Energy Open Access Regulations, 2024 support microgrids by enabling non-discriminatory grid access, allowing energy banking, and simplifying approvals for renewable projects. Flexible billing and net metering empower microgrid participants to produce and trade energy, while transparent transmission charges aid financial planning. Priority access for renewables and financial incentives encourage decentralized, sustainable energy growth. These regulations foster renewable-based microgrids, enhancing energy reliability and supporting Gujarat's goals for clean, resilient energy solutions [16].

These policies address unique state challenges and encourage local solutions, supporting sustainable energy development in diverse regions.

3. Microgrid Case Studies in India

Several case studies demonstrate the effectiveness of decentralized renewable systems in India.

- A significant project of NTPC Energy Technology Research Alliance (NETRA) involves the development of a large microgrid at NETRA's Greater Noida campus. This microgrid aims to enhance energy reliability and efficiency by integrating Distributed Energy Resources (DERs). The NETRA campus features interconnected microgrids with Distributed Energy Resources (DERs) based on diverse technologies, creating a robust and versatile energy ecosystem. These include a 4 MWp Solar PV system paired with a 1 MW/1 MWh Battery Energy Storage System (BESS), a 110 kW AC Microgrid, a 30 kW DC Microgrid, a 25 kW Fuel cell-based Hydrogen energy storage, a 400 kW Municipal Solid Waste (MSW) system, and cumulatively 296 kWp rooftop solar PV plants. Together, these systems demonstrate a range of cutting-edge renewable energy solutions, fostering resilience and sustainability on campus [17].

- Sundarbans, West Bengal: Initiatives like WWF-India's "Sahasra Jyoti" project and community-driven microgrids on the Kumirmari and Satjelia islands exemplify localized, community-led renewable systems providing reliable energy where grid extensions are impractical. By incorporating community-based management and prepaid metering, these projects have proven successful in maintaining financial sustainability [18].
- Jharkhand's Jargatoli and Basua Villages: Implemented by Mlinda Sustainable Environment Pvt. Ltd., these villages utilize a solar-diesel hybrid microgrid system to supply consistent electricity to 80% of households. The model includes prepaid meters and subsidized appliances to promote energy-efficient usage, thus addressing power reliability and affordability challenges [19].

These case studies reflect the adaptability and scalability of microgrid systems when tailored to local conditions, with significant impacts on local livelihoods, health, and economic opportunities.

4. Challenges in Scaling Microgrids and Mini grids

Despite the potential of decentralized energy, several obstacles remain:

4.1 Financial Viability

The capital expenditure for Rooftop Solar PV capex is approximately Rs 4-5 Cr/MW (Exclusive of land & evacuation system); Wind turbine generators is Rs 6-7 Cr/MW; BESS: Rs2-3 Cr/MWhr; micro/Small hydro is Rs 4-5 Cr/MW (Excluding land); cost of expertise for integrating DER's and BESS for microgrid is 1 Cr per microgrid.

The High installation costs, especially for storage components like batteries, elevate the per-unit cost of microgrid electricity especially when they are compared with DG sets power output. DG sets have lower upfront cost with high running cost. However, the BESS with higher upfront cost gives clean energy and helps maintain autonomous off-grid systems too.

4.2 Challenges in Deployment

Installing, commissioning, and stabilizing large Microgrids come with technical challenges. Installation issues include grid integration, integrating and controlling DER's, control of flexible loads to design the EMS is a bespoke solution which varies with the variety of DER's i.e solar PV, wind turbine generator, MSW generators, micro/small hydro plants. Extensive study of the various characteristics and constraints of each of these resources is studied for setting priority of resources for supplying base load and ramp up/ramp down operation.

Not just the sizing and control but operation and maintenance of the microgrids involves advanced skillset and expertise which is not available in remote areas which are suitable candidates for benefitting from this technology.

4.3 Technical and Operational Issues

Many rural areas experience voltage instability and technical limitations, complicating integration with the central grid. Further, scaling up the size of microgrid complicates the system which requires advanced expertise for integration and troubleshooting.

4.4 Policy Gaps and Inconsistencies

The Draft National Mini/Microgrid Policy (2016) remains unfinalized, creating policy uncertainty. Additionally, varying state-level policies and incentive structures can complicate the regulatory landscape for developers looking to operate across multiple states. Each state must have exhaustive policy for promoting this technology which would help reduce our dependency on DG Sets and add resilience to the power system democratizing the energy market of India.

5. Recommendations for Policy Enhancement to Scale Up Microgrids in India

To accelerate India's microgrid and mini-grid deployment, the following policy recommendations are proposed:

5.1 Finalization of National Microgrid Policy and Standardized Regulations

The government should finalize and implement the MNRE's Draft National Mini and Microgrid Policy with a clear roadmap, financial assistance through monetary and fiscal policies, skill development of local people to operate and maintain these futuristic technologies to develop communities.

Standardizing state-level regulations will simplify approvals, making investment processes smoother. Additionally, establishing a single-window clearance system for microgrid developers will help reduce delays and encourage faster deployment.

5.2 Financial Support and Incentives

To enhance the financial viability of microgrids, the government should increase capital subsidies for Battery Energy Storage Systems (BESS), hybrid microgrids, and smart grid technologies. Providing zero-interest or low-interest loans will further encourage private sector participation, particularly in off-grid regions. A Viability Gap Funding (VGF) mechanism can help bridge financial gaps for large-scale microgrid projects.

VGF funding, subsidy by the government, low-cost financing for deploying rooftop solar PV assisted by BESS of sufficient size to substitute DG Sets in commercial buildings, residential complexes will bring sea change in carbon footprints of commercial and institutional places of India.

5.3 Community Engagement and Capacity Building

Promoting community ownership models can improve the sustainability of microgrid projects. The government should establish training centers to develop a skilled workforce for installation, operation, and maintenance. Providing subsidies or tax incentives for rural consumers adopting microgrid power can make electricity more affordable and encourage greater adoption.

5.4 Research & Development Investments and Smart Grid Integration

Investing in cost-effective energy storage solutions, advanced microgrid controllers, and AI-driven load forecasting will improve efficiency and scalability. The government should support pilot projects for blockchain-based energy transactions and real-time monitoring systems to enhance reliability and security. Developing predictive maintenance frameworks using AI and IoT can ensure long-term operational stability.

6. Conclusion

Microgrids and DERs are pivotal for India's transition to sustainable energy, addressing rural electrification and energy security. While India's policy framework, including PM-Surya Ghar and state-specific initiatives, provides a foundation for microgrid expansion, challenges like high costs, policy inconsistencies, and technical constraints remain. Standardized guidelines, increased subsidies for storage, and community-centric models are essential to overcome these hurdles. Energy is going to be the next UPI and microgrid technologies integrating DER's with storage will be foundation of the Peer-to-Peer energy trading without congesting the distribution/sub transmission networks. Microgrids will improve the energy reliability and add resilience to remote and rural power distribution networks. They will help in restoration of the local power distribution systems, in events of natural calamities, independent of the central power grid. Successful projects like the one installed at NETRA demonstrate microgrids' potential to foster resilience and economic growth. A dedicated policy for promoting Micro, Mini and smart grid initiatives with energy storage is recommended, offering special tariff-based incentives to encourage power delivery during off-solar hours. This approach can enhance commercial and technical viability, ensuring reliable energy supply even when renewable resources are unavailable. By addressing policy gaps and encouraging local participation, India can achieve a robust, decentralized energy system aligned with its renewable energy and sustainability goals.

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