Journal of
Power Electronics & Power Systems
https://journals.stmjournals.com/jopeps
ISSN: 2249-863X (Online)
ISSN: 2321-4244 (Print)
Volume 15, Issue 3, 2025
September–December
DOI (Journal): 10.37591/JoPEPS
Research JoPEPS

Strategies for Efficient Integration of Distributed Energy Resources into Microgrid Systems

Saba Jafri[1], Kamaljeet Singh[2,*], Parwinder Singh[2]

Abstract

With the growing integration of Distributed Energy Resources into modern power systems, the global energy landscape is changing. Some of the DERs are solar photovoltaic (PV), wind turbines, battery storage systems, combined heat and power (CHP) units, and electric vehicles (EVs). Some of the advantages include lower transmission losses, better energy efficiency, and more resilience to grid failures. However, the far-reaching integration of DERs carries with it considerable technical, economic, and regulatory challenges that require resolution to create stable and sustainable power system operation. One crucial issue is how the intermittence of renewable generation sources causes shifts in electricity and poses risks against grid stability; unlike conventional power plants, traditional centralized power supply, DER does not have the inherent inertia responsible for voltage-fluctuation frequencies and power-quality issues. To mitigate these challenges, advanced forecasting techniques, energy storage solutions, demand response mechanisms, and AI-driven optimization strategies are crucial. Furthermore, regulatory uncertainties and high initial capital costs hinder DER deployment, necessitating innovative business models such as peer-to-peer energy trading, blockchain-based transactions, and dynamic pricing mechanisms. In addition, the growing use of digital communication and IoT-enabled devices increases concerns about cybersecurity and requires encryption, intrusion detection systems, and blockchain security protocols in protecting grid infrastructure. This necessitates a comprehensive approach that ties together technological, policy, and financial strategies toward a resilient, secure, and efficient DER-based energy ecosystem. This study looks into the major triggers, advantages and challenges that lie in DERs' integration in power grids besides some solutions with the promise to sustain the very decentralized energy.

Keywords: Distributed energy resources (DERs), microgrids, renewable energy integration, grid stability, energy storage, demand response, smart grids, blockchain energy trading, decentralized energy systems, energy trading, ai-driven optimization, regulatory frameworks, economic feasibility

INTRODUCTION

The energy systems of India are undergoing significant transformations in order to boost the country's supply of electricity, reduce emissions of greenhouse gases, and promote sustainability. Distributed energy resources (DERs) are examples of renewable energy sources that are now essential for the transformation. These DERs produce energy that is clean, reliable, and decentralized. Some examples of DERs are solar photovoltaic (PV), wind, bioenergy, and small hydro [1]. A growing number of people are turning to the use of microgrids as a means of delivering dependable electricity, enhancing the grid's capacity to withstand obstacles, and increasing the utilization of renewable energy sources in regions that are difficult to access. While distributed energy resources (DERs)-based microgrids offer a great deal of potential, there are a lot of challenges

***Author for Correspondence**
Kamaljeet Singh
E-mail: Kamaljeetbara022@gmail.com

[1]Post Graduate Student, Department of Electrical Engineering, I.K. Gujral Punjab Technical University, Jalandhar, Punjab, India
[2]Assistant Professor, Department of Electrical Engineering, I.K. Gujral Punjab Technical University, Jalandhar, Punjab, India

Received Date: June 23, 2025
Accepted Date: June 28, 2025
Published Date: August 07, 2025

Citation: Saba Jafri, Kamaljeet Singh, Parwinder Singh. Strategies for Efficient Integration of Distributed Energy Resources into Microgrid Systems. Journal of Power Electronics & Power Systems. 2025; 15(3): 51–56p.

involved in integrating them in India. Scaling and making efficient use of distributed energy resources (DERs) is made more difficult by factors such as differences in the availability of renewable resources, regional laws, the state of the grid, and financial concerns. On the other hand, solar energy is utilized by a large number of people, whilst waste-to-energy and tiny hydropower continue to be underutilized [2, 3]. In addition, the fact that each state has its own set of regulations on net metering and feed-in tariffs makes it more challenging for individuals to participate in microgrids and to successfully plan them for a large number of users.

With the help of this study, the integration of distributed energy resources (DER) in Indian microgrids will be investigated. This will be accomplished by examining the renewable energy installations, solar panels, and legislation that are in place in each state [4]. To evaluate the effectiveness, dependability, and economic viability of a variety of distributed energy resource (DER) configurations, the research makes use of both secondary data and simulation models. The findings are intended to provide guidance to policymakers, grid operators, and other stakeholders regarding how to enhance the integration of distributed energy resources (DER), coordinate policies, and support sustainable energy growth in India's power sector, which is undergoing significant change.

Concept of Distributed Energy Resources (DERS)

Distribution Energy Resources, often known as DERs, are energy systems that are located in close proximity to the point of consumption and provide an alternative to the generation of power in a centralized location. Solar photovoltaic (PV) systems, wind turbines, microturbines, fuel cells, energy storage systems, and other technologies such as electric vehicles and biomass generators are included in this category [5]. Distributed energy resources (DERs) improve energy efficiency by lowering transmission losses, boost grid independence and dependability by means of microgrids, and make effective demand-side management possible through the use of intelligent technology [6]. The promotion of cleaner energy sources and the reduction of emissions of greenhouse gases are two additional key environmental benefits that they make available. In general, distributed energy resources are necessary for the construction of an energy future that is flexible, sustainable, and resilient.

LITERATURE REVIEW

Basak *et al*. stated that using distributed energy resources (DERs) in microgrids will have a major role in upcoming power systems [1]. It talked about recent developments and future directions in microgrids from different places, pointing out that microgrids are gaining more importance in today's energy industry. Authors focused on crucial topics and outlined the important issues that need to be resolved to use microgrids in power systems. It was discovered that operating microgrids becomes troublesome because of many DERs and unpredictable scenarios that can appear during their operation, either alone or connected to the main grid. The authors believe that understanding these important aspects is necessary to make microgrids a reality.

Basak *et al*. initiated their future studies by studying what was known and looking into power quality problems and the risks of systems becoming unstable [1]. People working to better microgrid technology and connect them to the main power grid still use their study as a starting point.

Rahman *et al*. revealed that distributed energy resources (DERs) are very important for power grid development today [7]. They noted that DERs have a big impact on reducing greenhouse gases and power losses during transmission, and they also make the grid safer, more reliable and long-lasting. A clear list and short explanations of a variety of DER technologies were presented in the research, such as those that depend on fossil fuels, wind turbines, fuel cells, energy storage systems, and solar photovoltaic panels. The authors examined the special attributes of every resource to explain that mixing these different DERs supports both decentralization and sustainability in energy production. They make use of centralized, decentralized and distributed controls to enhance the way energy flows, keep the grid stable, and face issues caused by changes in renewable energy and electricity used. The authors looked closely at prior studies to find that the main issues included the lack of advanced control methods, strong communication systems and better coordination of distributed energy resources. By identifying these gaps, future studies can work on creating smarter, flexible and bigger solutions for DER integration [7].

Rangu *et al*. studied the problems linked to using solar and wind energy, as they might not be stable due to weather changes [8]. Because there is so much variability, those in charge of distributed networks have a harder time controlling and managing multi-microgrid systems that do not include fast-ramping technologies. Traditional methods were not enough to deal with the economic impacts of decisions in operations, so the authors explored various ways, both certain and uncertain, to manage renewable power. The research concentrated on coming up with the most suitable schedules for different energy sources in microgrids. The document provided information on the various techniques, advanced controls, and demand response tools that help a microgrid generate more profit. Also, the paper looked into distributed and decentralized control methods that help different generators cooperate well in various grid designs and kinds of networks. The review outlines the approaches that can assist microgrids in working better and at lower costs as technology advances [8].

Muhtadi *et al*. studied that microgrids based on DERs can help more DERs become useful in the current power grid [3]. They concentrated their studies on several aspects of microgrids using DER technology, such as important concepts, explanations and a detailed comparison of the primary, secondary and tertiary control strategies. The review also focused on how to manage energy and problems related to power quality as DERs are used. It was noted by the authors that microgrids become more reliable when ESS and EVs are used. To check the findings, simulations were run to see if solar and wind energy, ESS and EVs had the expected impact on the microgrid's frequency. I also performed more simulations to find out how the microgrid's reliability is influenced by DERs, ESS, EVs and the ways they are used. It gives information on how different DERs affect microgrids and the role of advanced approaches in ensuring their strength [3].

RESEARCH METHODOLOGY

Research Design

This research uses both types of data analysis and policy assessments to fully review the integration of Distributed Energy Resources (DERs) in Indian microgrids. Researchers systematically collect, simulate, and interpret data on renewable energy as well as analyze relevant policies to discover what affects the deployment and use of DER [9].

Data Collection

- *Secondary data*: All the information about installed renewable energy capacities, rooftop solar deployments, and net metering policies in Indian states was taken from reliable government reports, industry databases, and agencies such as MNRE, CEA, and various State Renewable Energy Departments [10].
- *Simulated data*: Investigations were carried out by developing simulations of microgrids with DER elements in MATLAB/Simulink and HOMER Pro to study the system's performance under a range of DER penetration and grid circumstances.

Data Parameters

- Installed Capacity (GW) of various renewable sources including solar, wind, bio-energy, small hydro, and waste-to-energy.
- Rooftop Solar Capacity (MW) by state is used to analyze differences in areas and the trend of its use.
- Policies on Net Metering, including the maximum amount allowed and feed-in tariffs, to check how these factors affect the use of DERs.
- The level of energy efficiency, reliability, and cost-effectiveness of a microgrid in different DER integration conditions.

Data Analysis

Collected and simulated data is analyzed by using descriptive statistics, checking performance, and regression analysis. The process of comparing shows what varies between different SPV and battery management control setups. Regression models determine how environmental elements influence how much energy is produced [11].

DATA ANALYSIS AND INTERPRETATION

This section presents a systematic examination of the collected and simulated data to evaluate the performance and effectiveness of Distributed Energy Resources integration in Indian microgrids.

Installed Renewable Energy Capacity in India

As shown in Table 1, India's overall renewable energy (RE) capacity was 132.79 GW by 2023. Additionally, Figure 1 shows the renewable energy capacity in India.

More than half of the total renewable energy mix comes from solar which has an installed capacity of 72.31 GW. Wind energy has a capacity of 44.73 GW, then comes bio-energy with 10.29 GW and small hydro power with 4.94 GW. Waste-to-energy accounts for only about 0.52 GW of the total capacity. This picture shows that governments are doing a lot to support solar energy, mainly in regions with high sunlight [12]. The government has focused its policy on solar parks, rooftop solar and grid-connected solar microgrids which makes solar energy the main part of India's renewable energy plan. Nevertheless, since small hydro and waste-to-energy have not advanced much, it is clear that the range of DERs could be improved to ensure a stable supply and avoid uneven distribution of energy.

State-wise Rooftop Solar Deployment

Table 2 looks at rooftop solar adoption in each state. Furthermore, Figure 2 represents the state-wise rooftop solar adoption.

Table 1. Renewable Energy Capacity in India.

Source	Installed capacity (GW)
Solar Power	72.31
Wind Power	44.73
Bio-energy	10.29
Small Hydro Power	4.94
Waste-to-Energy	0.52
Total RE Capacity	132.79

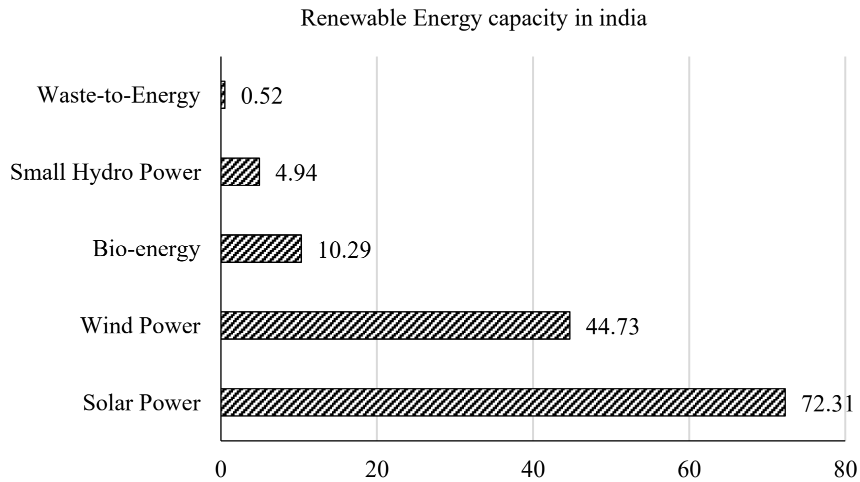

Figure 1. Renewable energy capacity in India.

Table 2. State-wise rooftop solar adoption.

State	Rooftop installed capacity (MW)
Gujarat	1250
Tamil Nadu	980
Karnataka	920
Maharashtra	870

Table 3. Net metering policy comparison.

State	Net metering limit (kW)	Feed-in tariff (₹/kWh)
Delhi	20	3.0
Rajasthan	50	2.8
Kerala	10	3.2
Punjab	30	2.9

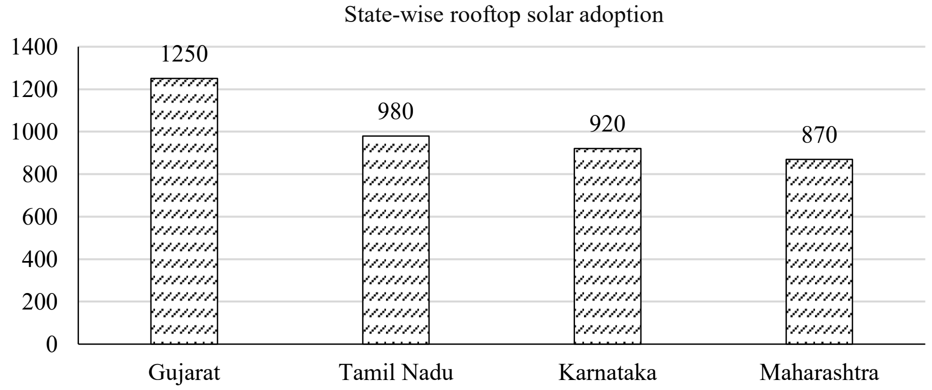

Figure 2. State-wise rooftop solar adoption.

Gujarat is ranked first among the leading states with 1250 MW of rooftop solar capacity and Tamil Nadu comes in second with 980 MW, followed by Karnataka (920 MW) and Maharashtra (870 MW). They have become leaders because of their active policies, the help of distribution companies, effective use of subsidies and successful awareness campaigns [13]. As an example, the Surya Urja Rooftop Yojana in Gujarat encourages people and institutions to install solar panels, leading to its wide acceptance. In the same way, Tamil Nadu and Karnataka have encouraged the use of rooftop solar in industrial areas and commercial sectors. This data points out that the amount of DER integration in India varies from one place to another, depending on local policies, the economy of consumers and the capacity of the grid. High-performing states have proven scalability and this makes it possible for lagging regions to benefit from their policies, especially while developing microgrids that use DER [14].

Policy Disparities in Net Metering Across States

Table 3 compares net metering policies in some Indian states by looking at the maximum capacity allowed and the feed-in tariffs (₹/kWh) for surplus energy sent to the grid. There are many differences in the policies from state to state. In Rajasthan, the net metering limit is 50 kW which means medium-sized commercial users are encouraged to take part in decentralized solar production. Kerala, on the other hand, only allows up to 10 kW which discourages using solar energy on a large scale in housing estates and small enterprises. The guidelines set in Delhi and Punjab are 20 and 30 kW, respectively [15]. Moreover, feed-in tariffs are set between ₹2.8 and ₹3.2/kWh which affects the investment's profitability. Even though Kerala has the highest feed-in tariff, its low capacity limit is not very attractive. Different regulations in each state make it difficult for consumers to understand and stop national-level planning for DER-microgrid integration. Creating a unified policy would greatly speed up the use of rooftop solar and microgrids.

CONCLUSION

The study highlights that Distributed Energy Resources should be effectively added to Indian microgrids to benefit the country's plans for renewable energy. It is clear from the study that solar energy is far ahead, but there are big regional differences due to different policies and the condition of the grids. Results from simulation show that when DERs are tuned well, microgrids perform better in terms of energy efficiency, reliability, and how cost-effective they are. Still, because there is no standard net metering policy and DER portfolios are not very diverse, it is tough to expand microgrid solutions to many places. To solve these problems, India requires an equal regulatory system, as well as focused rewards and new technology, to make sure DERs help create a stable and lasting energy supply. The study supplies helpful information for those who want to support microgrids and promote a greener energy sector.

REFERENCES

1. Basak P, Chowdhury S, Dey SHN, Chowdhury SP. A literature review on integration of distributed energy resources in the perspective of control, protection and stability of microgrid. Renew Sustain Energy Rev. 2012; 16(8): 5545–56.
2. Gholami S, Saha S, Aldeen M. Fault tolerant control of electronically coupled distributed energy resources in microgrid systems. Int J Electr Power Energy Syst. 2018; 95: 327–40.
3. Muhtadi A, Pandit D, Nguyen N, Mitra J. Distributed energy resources based microgrid: Review of architecture, control, and reliability. IEEE Trans Ind Appl. 2021; 57(3): 2223–35.
4. Nunna HK, Doolla S. Multiagent-based distributed-energy-resource management for intelligent microgrids. IEEE Trans Ind Electron. 2012; 60(4): 1678–87.
5. Otshwe JN, Li B, Chen S, Gong F, Qi B, Chabrol NJ. Adaptive control and market integration: Optimizing distributed power resources for a sustainable grid. Energies. 2025; 18(7): 1658.
6. Panda S, Mohanty S, Rout PK, Sahu BK, Parida SM, Kotb H, *et al*. An insight into the integration of distributed energy resources and energy storage systems with smart distribution networks using demand-side management. Appl Sci. 2022; 12(17): 8914.
7. Rahman HA, Majid MS, Jordehi AR, Kim GC, Hassan MY, Fadhl SO. Operation and control strategies of integrated distributed energy resources: A review. Renew Sustain Energy Rev. 2015; 51: 1412–20.
8. Rangu SK, Lolla PR, Dhenuvakonda KR, Singh AR. Recent trends in power management strategies for optimal operation of distributed energy resources in microgrids: A comprehensive review. Int J Energy Res. 2020; 44(13): 9889–911.
9. Ren F, Wei Z, Zhai X. A review on the integration and optimization of distributed energy systems. Renew Sustain Energy Rev. 2022; 162: 112440.
10. Rezaeimozafar M, Eskandari M, Amini MH, Moradi MH, Siano P. A bi-layer multi-objective techno-economical optimization model for optimal integration of distributed energy resources into smart/micro grids. Energies. 2020; 13(7): 1706.
11. Sarmiento-Vintimilla JC, Torres E, Larruskain DM, Pérez-Molina MJ. Applications, operational architectures and development of virtual power plants as a strategy to facilitate the integration of distributed energy resources. Energies. 2022; 15(3): 775.
12. Semero YK, Zhang J, Zheng D. Optimal energy management strategy in microgrids with mixed energy resources and energy storage system. IET Cyber Phys Syst Theory Appl. 2020; 5(1): 80–4.
13. Xu Y, Zhang W, Hug G, Kar S, Li Z. Cooperative control of distributed energy storage systems in a microgrid. IEEE Trans Smart Grid. 2014; 6(1): 238–48.
14. Yuan C, Illindala MS, Khalsa AS. Co-optimization scheme for distributed energy resource planning in community microgrids. IEEE Trans Sustain Energy. 2017; 8(4): 1351–60.
15. Yuvaraj T, Devabalaji KR, Suresh TD, Prabaharan N, Ueda S, Senjyu T. Enhancing Indian practical distribution system resilience through microgrid formation and integration of distributed energy resources considering battery electric vehicle. IEEE Access. 2023; 11: 133521–39.

