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Hybrid Solar-Wind Microgrid Systems for Rural Electrification: A Comparative Analysis

Author:
Dr. Kunal Deshpande
Department of Electrical and Renewable Energy Engineering
Greenfield University of Technology
Pune, India

Email: kunal.deshpande@gutu.edu.in

Abstract

Energy access remains a critical challenge in rural regions, where grid extension is often economically and technically unfeasible. Hybrid microgrid systems integrating solar photovoltaic (PV) and wind energy have emerged as promising solutions for decentralized electrification. This paper presents a comparative analysis of hybrid solar-wind microgrid systems, evaluating their technical performance, cost efficiency, and sustainability. Using HOMER Pro software, simulations were conducted on various load profiles typical of rural communities. Results show that hybrid systems achieve a 30–40% reduction in Levelized Cost of Energy (LCOE) compared to diesel-based systems, while ensuring improved energy stability. The findings suggest that hybrid microgrids represent a sustainable pathway to achieve universal energy access in developing economies.

Keywords: Hybrid Microgrid, Solar Energy, Wind Power, Rural Electrification, Renewable Energy Systems.

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1. Introduction

Reliable access to electricity is essential for socio-economic development, yet over 700 million people worldwide, primarily in rural areas, remain without reliable energy access (IEA, 2022).

Extending national grids to remote villages is often economically prohibitive due to high infrastructure costs, geographical barriers, and low energy demand density.

Hybrid microgrids, combining renewable energy resources such as solar and wind, provide a decentralized and sustainable solution. Solar PV is abundant and cost-effective, while wind energy offers complementary generation, particularly during off-peak solar hours. This paper investigates the potential of hybrid solar-wind microgrid systems to provide sustainable rural electrification.

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2. Literature Review

Existing literature highlights the promise of hybrid energy systems. Bhattacharya et al. (2017) demonstrated cost reductions when combining PV with wind power in isolated communities. Mandal et al. (2019) emphasized the environmental benefits of hybrid microgrids compared to diesel generators.

However, challenges remain in system optimization, seasonal variability, and battery storage costs. Recent advances in power electronics and microgrid controllers have made hybrid systems more viable. Yet, limited comparative studies exist across different rural load scenarios. This research contributes by evaluating hybrid systems against conventional and single-source renewable options.

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3. Methodology

The study employs a simulation-based approach using **HOMER Pro** to design and analyze hybrid solar-wind microgrid systems.

Parameters Considered:

- **Solar PV Capacity:** 50–150 kW

- **Wind Turbine Capacity:** 30–80 kW
- **Battery Storage:** Lithium-ion (100–500 kWh)
- **Diesel Generator (backup):** 30 kW

Case Studies:

- **Village A:** Agricultural load (daytime intensive)
- **Village B:** Residential load (evening peak demand)
- **Village C:** Mixed load (schools, healthcare, small businesses)

Evaluation Metrics:

- Levelized Cost of Energy (LCOE)
- Renewable Fraction (%)
- CO_2 Emission Reduction
- Reliability Index (Loss of Power Supply Probability – LPSP)

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4. Results

Simulation results indicate that hybrid systems outperform single-source and diesel-based alternatives.

- **Village A:** Solar-dominant with wind support reduced LCOE to **$0.12/kWh**, with a 70% renewable fraction.

- **Village B:** Wind contribution during evening peaks stabilized supply; LCOE **$0.14/kWh**, CO_2 emissions reduced by 85%.

- **Village C:** Optimal hybrid mix achieved **95% reliability** and lowest emissions.

Compared to diesel-only microgrids, hybrid systems reduced costs by **35%** and CO_2 emissions by **over 80%**.

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5. Discussion

The analysis demonstrates the feasibility and advantages of hybrid solar-wind microgrids for rural electrification. The complementary nature of solar and wind generation ensures higher reliability. However, the success of such systems depends on appropriate sizing, seasonal resource assessment, and cost-effective battery integration.

Policy support, subsidies, and community participation are critical for scaling up deployment. Hybrid systems not only provide clean energy but also stimulate rural economic activities such as irrigation, refrigeration, and small-scale industries.

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6. Conclusion

Hybrid solar-wind microgrids represent a sustainable and cost-effective solution for rural electrification. The study's comparative analysis confirms their technical and economic superiority over diesel-based systems. Future research should focus on advanced energy storage, smart microgrid controllers, and financial models to enhance adoption in developing countries.

References

1. Bhattacharya, S., et al. (2017). *Hybrid renewable energy systems for off-grid rural electrification: A case study*. Renewable Energy.

2. Mandal, S., et al. (2019). *Performance assessment of hybrid microgrid systems for sustainable energy access*. Energy Policy.

3. International Energy Agency (IEA). (2022). *World Energy Outlook*.

4. Homer Energy. (2021). *HOMER Pro User Manual*.