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Integrated solar-wind hybrid systems for decentralized rural electrification: A techno-economic review.

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Introduction

Access to reliable and affordable electricity remains a critical development challenge in many rural and remote areas around the world. Despite advances in grid expansion, over 700 million people—mostly in Sub-Saharan Africa and parts of Asia—still lack access to electricity. In this context, integrated solar-wind hybrid systems have emerged as a promising solution for decentralized rural electrification, offering a clean, cost-effective, and sustainable alternative to fossil-fuel-based or grid-dependent systems. This article reviews the technological components, economic feasibility, and implementation challenges of solar-wind hybrid systems in rural electrification projects [1].

Rural areas often suffer from geographical isolation, low population density, and poor infrastructure, making conventional grid extension technically and economically unviable. Decentralized energy systems—especially renewable-based microgrids—offer the flexibility to generate electricity close to the point of use, reducing transmission losses and ensuring energy autonomy. Among various renewable options, solar and wind energy are abundant, complementary, and increasingly cost-competitive, making their integration a smart strategy for reliable power supply [2].

One of the main advantages of hybrid solar-wind systems lies in the natural complementarity of the resources. Solar power is typically available during the day and strongest during the dry season, while wind energy is often stronger at night or during monsoon seasons, depending on the region. This temporal balance helps reduce the intermittency and variability that affects standalone renewable systems. When combined with battery storage, solar-wind hybrids can ensure round-the-clock electricity supply with minimal reliance on backup generators [3].

A typical solar-wind hybrid system consists of photovoltaic (PV) panels, wind turbines, battery energy storage, inverters, and a hybrid controller. The controller plays a central role in optimizing power flows, managing load demand, and protecting the system from overcharging or discharging. Hybrid systems can be designed for off-grid, mini-grid, or grid-tied configurations, depending on the energy demand, resource availability, and local infrastructure [4].

Proper system sizing and optimization are crucial for performance and cost-effectiveness. Tools like HOMER (Hybrid Optimization of Multiple Energy Resources) and MATLAB-based simulation models are widely used to evaluate system configurations based on resource data, load profiles, and economic constraints. Factors such as solar irradiance, wind speed, daily energy demand, and storage capacity must be carefully analyzed to avoid under-sizing (which leads to blackouts) or over-sizing (which inflates costs) [5].

Conclusion

Integrated solar-wind hybrid systems represent a practical and scalable solution for decentralized rural electrification, especially in regions with limited grid access. By leveraging the complementary strengths of solar and wind energy, these systems can deliver reliable, clean, and cost-effective power to underserved communities. While technical and financial challenges remain, strong policy support, innovative business models, and community engagement can unlock their full potential—bringing us closer to universal energy access and a low-carbon future.

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