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Mathematical Modelling and Simulation of AI-Enhanced Off-Grid Renewable Energy Systems for Optimal Sizing, Cost Reduction, and Reliability Improvement

Communication Info

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Abstract

Off-grid solar photovoltaic (PV) systems are increasingly deployed to electrify remote and underserved communities; however, their performance is often constrained by suboptimal system sizing, inefficient energy management, battery degradation, and limited reliability [1]. This study presents a mathematical modelling and simulation-based optimization framework for AI-enhanced off-grid PV systems to improve efficiency, cost-effectiveness, and operational reliability. Mathematical models are formulated for the PV array, battery energy storage, charge controller, and load demand, incorporating energy balance equations, state-of-charge dynamics, degradation behavior, and power-flow constraints [2]- [3]. Machine learning techniques forecast solar irradiation and load demand, while optimization algorithms regulate charge–discharge cycles [4]-[5]. Simulation results demonstrate a 22% increase in battery lifespan, 18% reduction in energy losses, 15% decrease in system cost, and 30% reduction in downtime, outperforming conventional and recent AI-based approaches.

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