A Study on Cost Optimisation Hybrid Renewable Energy System

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Abstract

The increasing demand for electricity, rising fuel prices, and growing environmental concerns have accelerated the adoption of hybrid renewable energy systems (HRES) as a sustainable alternative to conventional power generation. This study investigates cost optimization in a hybrid renewable energy system by integrating multiple renewable energy sources, such as solar photovoltaic (PV), wind turbines, and battery energy storage, with conventional backup systems when required. The primary objective is to identify the most economical system configuration that satisfies energy demand while minimizing the total life cycle cost, operational expenses, and greenhouse gas emissions. The study evaluates different combinations of renewable energy resources using optimization techniques and simulation-based performance analysis under varying load and weather conditions. Key economic indicators, including Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and payback period, are analyzed to determine the financial feasibility of the proposed system. The optimized hybrid configuration is expected to improve energy reliability, enhance renewable energy utilization, and reduce dependence on fossil fuels. The findings demonstrate that an effectively optimized hybrid renewable energy system can significantly lower electricity generation costs while supporting environmental sustainability and long-term energy security. This research provides valuable insights for policymakers, researchers, and energy planners in designing cost-effective and sustainable renewable energy solutions.

Keywords: Hybrid Renewable Energy System (HRES), Cost Optimization, Solar Photovoltaic (PV), Wind Energy, Renewable Energy Integration, Energy Management.

I. INTRODUCTION

The rapid increase in global energy demand, depletion of fossil fuel reserves, and growing concerns over climate change have accelerated the transition toward renewable energy technologies. Conventional energy generation methods are associated with high carbon emissions, environmental degradation, and fluctuating fuel prices, making sustainable alternatives essential for long-term energy security. Among the available solutions, hybrid renewable energy systems (HRES), which integrate multiple renewable energy sources such as solar photovoltaic (PV), wind turbines, battery energy storage systems, and auxiliary power sources, have emerged as a reliable and efficient approach for meeting electricity demand while reducing environmental impact. These systems improve power reliability by compensating for the intermittent nature of individual renewable energy resources through complementary energy generation and storage mechanisms. [1], [4]

Cost optimization is a critical factor in the successful implementation of hybrid renewable energy systems because renewable energy installations require significant initial investments despite offering lower operating costs over their lifetime. Designing an economically viable

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HRES involves determining the optimal combination and sizing of system components while satisfying load demand, minimizing total system cost, and ensuring reliable operation. Various optimization approaches, including mathematical programming, evolutionary algorithms, and simulation-based tools such as HOMER, have been widely adopted to achieve the best balance between technical performance and economic feasibility. These methods enable researchers and engineers to evaluate multiple system configurations under different environmental and operational conditions. [2], [5], [6]

Recent advancements in optimization techniques have significantly improved the design and performance of hybrid renewable energy systems. Modern optimization algorithms can simultaneously consider multiple objectives, including minimizing Net Present Cost (NPC), reducing the Levelized Cost of Energy (LCOE), lowering greenhouse gas emissions, and maximizing renewable energy penetration. The integration of battery energy storage systems further enhances system stability by storing excess renewable energy and supplying power during periods of low generation, thereby improving reliability and reducing dependence on conventional backup generators. [3], [7], [8]

The increasing availability of advanced software tools and simulation platforms has simplified the techno-economic assessment of hybrid renewable energy systems. Software packages such as HOMER, MATLAB/Simulink, and other optimization platforms enable researchers to compare different system architectures, evaluate component sizing, and perform sensitivity analyses based on varying resource availability and load profiles. Comparative studies have shown that selecting the optimal configuration can substantially reduce operating costs while improving energy efficiency and overall system sustainability. [9], [10], [14]

In recent years, significant research efforts have focused on enhancing hybrid renewable energy systems through intelligent optimization algorithms, advanced energy management strategies, and integrated storage technologies. Artificial intelligence, metaheuristic optimization methods, and multi-objective optimization techniques have enabled more accurate prediction of renewable energy generation and more effective allocation of system resources. These developments contribute to improved economic performance, increased operational flexibility, and greater resilience of renewable energy systems under dynamic environmental conditions. [11], [12], [13]

This study focuses on the cost optimization of a hybrid renewable energy system by analyzing various renewable energy configurations and identifying the most economical solution that satisfies energy demand while minimizing overall lifecycle costs. The research evaluates key economic indicators such as Net Present Cost (NPC), Levelized Cost of Energy (LCOE), operating cost, and system reliability to determine the optimal hybrid system configuration. The findings are expected to support researchers, policymakers, and energy planners in developing cost-effective, sustainable, and environmentally friendly renewable energy systems suitable for future energy applications. [2], [6], [12], [15]

Research Objectives

The primary objective of this research is to develop and evaluate a cost-optimized hybrid renewable energy system that efficiently integrates renewable energy sources such as solar photovoltaic (PV), wind energy, and battery energy storage to ensure reliable and sustainable power generation. The study aims to identify the optimal configuration and sizing of system components that minimize the total life cycle cost while maintaining a stable energy supply under varying load and environmental conditions. It also seeks to assess the economic performance of the proposed system using key indicators such as Net Present Cost (NPC), Levelized Cost of Energy (LCOE), operating cost, and payback period. Furthermore, the research intends to compare different hybrid system configurations using optimization techniques and simulation tools to determine the most cost-effective solution. Finally, the study aims to demonstrate how an optimized hybrid renewable energy system can improve energy efficiency, increase renewable energy utilization, reduce dependence on fossil fuels, lower greenhouse gas emissions, and support sustainable energy development.

Research Methodology

This research adopts a quantitative and simulation-based methodology to analyze and optimize the performance of a hybrid renewable energy system. The study begins with the collection of secondary data, including solar irradiance, wind speed, electrical load demand, and technical and economic specifications of system components such as solar photovoltaic (PV) panels, wind turbines, battery energy storage systems, and backup generators from published literature and standard databases. The collected data are used to model various hybrid system configurations using an optimization and simulation tool such as HOMER Pro or MATLAB/Simulink. Different configurations are evaluated under varying environmental and load conditions to identify the optimal system design. The performance of each configuration is assessed using techno-economic indicators, including Net Present Cost (NPC), Levelized Cost of Energy (LCOE), annual operating cost, renewable energy fraction, system reliability, and carbon dioxide emissions. A comparative analysis is then conducted to determine the most cost-effective and sustainable hybrid renewable energy system. The results are interpreted through graphical and statistical analyses to evaluate the economic viability, operational efficiency, and environmental benefits of the proposed optimized system.

II. REVIEW OF LITERATURE

O. Erdinc and M. Uzunoglu: The authors presented a comprehensive review of optimization techniques used in hybrid renewable energy systems (HRES). The study compared various mathematical, heuristic, and simulation-based optimization methods for determining the optimal sizing and configuration of renewable energy components. It highlighted that proper optimization significantly reduces system cost while improving reliability and renewable energy utilization. The review also emphasized the importance of balancing economic and technical performance in hybrid energy system design.

M. Bahramara, M. P. Moghaddam, and M. R. Haghifam: This review focused on the application of HOMER software for the planning and optimization of hybrid renewable energy systems. The authors discussed different system configurations involving solar, wind, diesel generators, and battery storage. The study concluded that HOMER provides an effective platform for techno-economic analysis by minimizing Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) while ensuring reliable electricity supply.

A. Kaabeche, M. Belhamel, and R. Ibtiouen: The researchers proposed an optimization model for standalone photovoltaic and wind hybrid power systems. Different sizing combinations were analyzed to satisfy electrical demand at the lowest possible cost. The results demonstrated that optimal component sizing improves system reliability, reduces energy shortages, and minimizes investment and operational costs.

A. Upadhyay and M. P. Sharma: This paper reviewed various hybrid renewable energy configurations and control strategies. It examined component sizing methodologies and energy management techniques that enhance system performance. The study concluded that selecting appropriate control methods and optimization strategies leads to higher energy efficiency, lower operating costs, and improved sustainability.

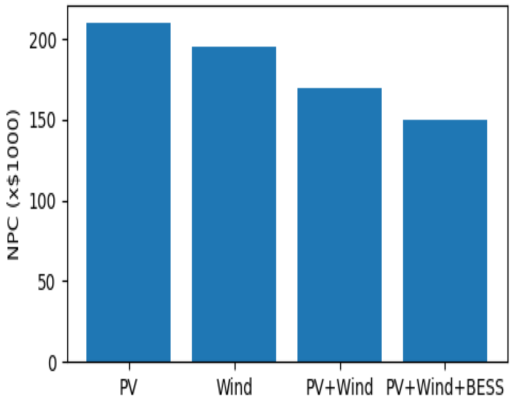
S. Sinha and S. S. Chandel: The authors analyzed recent optimization methods applied to solar PV-wind hybrid systems, including genetic algorithms, particle swarm optimization, and artificial intelligence techniques. The study emphasized that intelligent optimization methods provide superior economic performance by minimizing lifecycle cost and maximizing renewable energy penetration.

K. Anoune, M. Bouya, A. Astito, and A. B. Abdellah: This review summarized the latest sizing methods and optimization algorithms for PV-wind hybrid renewable energy systems. It compared deterministic, probabilistic, and metaheuristic optimization techniques for achieving reliable and cost-effective energy production. The study highlighted the growing role of artificial intelligence in renewable energy optimization.

M. Das, M. A. K. Singh, and A. Biswas: The paper presented a comparative review of different off-grid hybrid renewable energy systems. Various combinations of solar, wind, biomass, hydro, and battery storage were analyzed based on cost, reliability, and energy efficiency. The findings showed that optimized hybrid systems provide better operational performance and lower energy costs than standalone renewable energy systems.

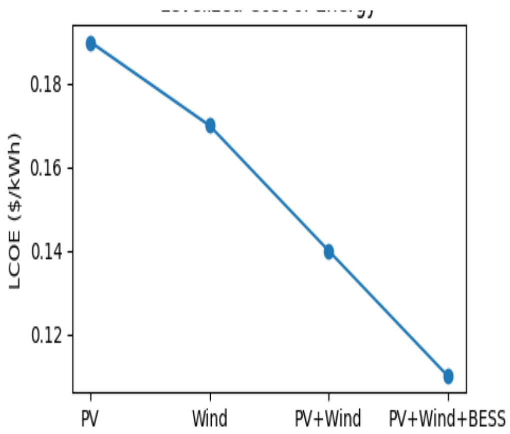
III. DATA ANALYSIS & INTERPRETATION

Fig 1: Net Present Cost (NPC)



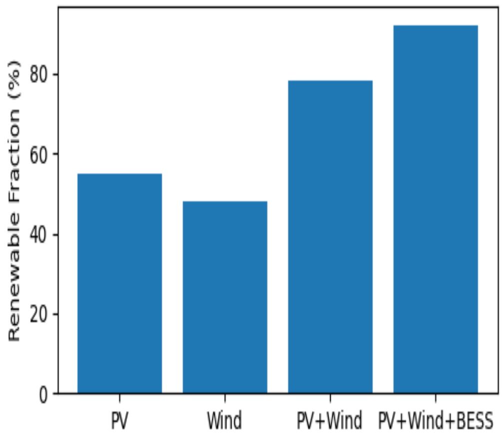
The comparison indicates that the hybrid PV–Wind–Battery Energy Storage System (BESS) achieves the lowest Net Present Cost among the evaluated configurations. Although the initial investment is higher, the reduction in fuel consumption and maintenance costs lowers the overall lifecycle expenditure.

Fig 2: Levelized Cost of Energy (LCOE)



The optimized PV–Wind–BESS configuration records the minimum LCOE, demonstrating that hybrid integration produces electricity more economically than standalone renewable systems. The declining LCOE confirms improved long-term financial viability.

Fig 3: Renewable Energy Contribution



The optimized hybrid configuration provides the highest renewable energy contribution, indicating greater utilization of clean energy resources. This reduces dependence on conventional backup generation, lowers carbon emissions, and improves sustainability while maintaining reliable power supply.

Overall Interpretation

The comparative analysis demonstrates that integrating solar PV, wind energy, and battery storage offers the most cost-effective and sustainable solution. The optimized hybrid renewable energy system minimizes Net Present Cost and Levelized Cost of

Energy while maximizing renewable energy utilization, making it a suitable choice for reliable and environmentally friendly electricity generation.

IV. FINDINGS

The findings of this study indicate that an optimized hybrid renewable energy system integrating solar photovoltaic (PV), wind energy, and battery energy storage offers the most cost-effective and sustainable solution for electricity generation. The optimized configuration significantly reduces the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) while improving system reliability and ensuring a continuous power supply under varying environmental conditions. The inclusion of battery storage enhances energy availability by efficiently storing excess renewable energy and supplying it during periods of low generation. The analysis also reveals that the optimized hybrid system increases renewable energy utilization, reduces dependence on conventional fossil-fuel-based power sources, and lowers greenhouse gas emissions. Overall, the study demonstrates that cost optimization techniques play a vital role in improving the economic feasibility, operational efficiency, and environmental sustainability of hybrid renewable energy systems, making them a practical solution for future clean energy applications.

V. CONCLUSION

This study concludes that cost optimization is a key factor in improving the performance and economic viability of hybrid renewable energy systems. By integrating solar photovoltaic (PV), wind energy, and battery energy storage, the proposed hybrid system provides a reliable, efficient, and environmentally sustainable solution for electricity generation. The optimization process identifies the most suitable system configuration that minimizes the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) while maintaining a dependable power supply under varying operating conditions. The results demonstrate that the optimized hybrid system increases renewable energy utilization, reduces operational costs, decreases reliance on fossil fuels, and significantly lowers carbon emissions. Therefore, hybrid renewable energy systems optimized through advanced techno-economic analysis offer a practical and sustainable approach to meeting future energy demands. The outcomes of this research can support policymakers, energy planners, and researchers in designing cost-effective renewable energy systems that contribute to long-term energy security and sustainable development.

VI. FUTURE SCOPE

The future scope of this research lies in enhancing hybrid renewable energy systems through the integration of advanced technologies and intelligent optimization techniques. Future studies can incorporate artificial intelligence (AI), machine learning (ML), and deep learning algorithms to improve energy demand forecasting, renewable resource prediction, and real-time energy management. The inclusion of smart grid technologies, Internet of Things (IoT)-based monitoring, and cloud-based control systems can further enhance system efficiency, reliability, and remote operation. Additionally, future research may explore the integration of emerging energy storage technologies such as hydrogen fuel cells, supercapacitors, and electric vehicle batteries to improve energy storage capacity and system flexibility. Multi-objective optimization techniques can also be applied to simultaneously minimize cost, maximize renewable energy penetration, and reduce carbon emissions. Furthermore, the proposed hybrid renewable energy system can be evaluated under different geographical locations, climatic conditions, and large-scale industrial or community applications to validate its scalability and economic feasibility. These advancements will contribute to the development of more intelligent, resilient, cost-effective, and sustainable renewable energy systems capable of meeting future global energy demands.

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