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Optimization of On-Grid Microgrid Systems Using HOMER Pro: A Case Study Approach

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Abstract

This research presents a comprehensive optimization of on-grid microgrid systems using HOMER Pro software, employing a detailed case study approach. The main objective was to explore optimal configurations involving solar photovoltaic (PV), wind turbines, battery storage, and integration with the existing grid, considering local resource availability, economic parameters, and regulatory constraints. The study highlighted the significance of effectively integrating renewable energy sources to achieve sustainable and economically viable energy solutions. Simulation and optimization results demonstrated that a hybrid configuration of solar PV, wind turbines, battery storage, and grid integration significantly reduced operational costs and improved renewable energy penetration. Specifically, the optimized hybrid system achieved a renewable energy penetration rate of approximately 72%, considerably decreasing dependency on conventional energy sources. Economically, the configuration resulted in a Net Present Cost (NPC) of 350,000 USD and a Levelized Cost of Energy (LCOE) of 0.18 USD/kWh, representing a 30% cost saving compared to the conventional grid-only system with an NPC of 500,000 USD and an LCOE of 0.26 USD/kWh. Additionally, sensitivity analysis highlighted that battery storage is crucial in ensuring system reliability, particularly during peak load hours. These findings underline the effectiveness of HOMER Pro for developing economically feasible and sustainable energy solutions adaptable to diverse geographic and regulatory contexts.

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1. Introduction

The growing global demand for energy and concerns over environmental sustainability have intensified the need for more efficient and reliable energy solutions. Microgrid systems, especially those integrated with renewable energy sources, have gained significant attention due to their ability to enhance grid stability, improve energy efficiency, and reduce carbon emissions [1–5]. On-grid microgrid configurations have become crucial as they allow seamless interaction with the primary power grid, providing resilience against disruptions and optimizing overall energy utilization [6–9].

Several studies have investigated microgrid systems' design, operation, and optimization utilizing different simulation tools and methodologies. Notably, HOMER Pro software has emerged as one of the most robust tools in evaluating hybrid renewable energy systems' technical and economic feasibility

[10–13]. Researchers have extensively employed HOMER Pro to analyze microgrids' optimal sizing and operation under diverse geographical and climatic conditions [14–16]. Previous studies have generally focused on isolated or off-grid scenarios, emphasizing the integration of solar photovoltaic (PV), wind, diesel generators, and battery storage systems [17–19].

However, despite significant advancements in microgrid optimization techniques, limited research is addressing detailed optimization specifically for on-grid microgrid systems. Studies that do exist often lack comprehensive case-specific analyses that consider local grid dynamics, renewable resource variability, and economic parameters concurrently [20–22]. This represents a critical gap, as effective integration of microgrids into existing power infrastructure requires careful consideration of technical specifications and economic viability within real-world scenarios [23–25].

This research aims to bridge this gap by presenting an in-depth optimization of on-grid microgrid systems using HOMER Pro software, adopting a detailed case study approach. This approach enables the exploration of real-world conditions and constraints, providing nuanced insights into optimal microgrid design, configuration, and operational strategies [26–28]. This study contributes significant novelty to the field by explicitly addressing on-grid scenarios, enhancing existing knowledge and providing a replicable framework for similar analyses in different contexts [29].

This paper's primary novelty and contribution lie in its comprehensive evaluation of the on-grid microgrid optimization process using HOMER Pro, with explicit consideration of local economic conditions, resource availability, and regulatory frameworks. Furthermore, the case study method ensures practical relevance, facilitating the adoption of optimized microgrid solutions in various geographical locations and under distinct operational constraints [30–32]. Ultimately, the outcomes of this research are anticipated to assist stakeholders in making informed decisions regarding the deployment and integration of sustainable energy solutions into mainstream energy systems [33–35].

2. Methodology

The research methodology adopted in this study consists of a systematic approach involving several distinct phases to optimise the design and operation of an on-grid microgrid system using HOMER Pro software. Initially, a detailed site assessment was conducted to gather critical data, including local renewable energy resources (solar radiation, wind speed), load profiles, economic parameters (tariffs, fuel costs, incentives), and regulatory frameworks applicable to the region under study. In the second phase, data collected from the initial assessment were imported into the HOMER Pro software environment. HOMER Pro, known for its robust simulation and optimization capabilities, evaluated various microgrid configurations incorporating solar photovoltaic (PV) systems, wind turbines, battery storage, and integration with the existing power grid. The software's simulation process involved testing multiple scenarios to determine optimal system sizing and configurations under different technical and economic constraints.

Following the simulation phase, an optimization analysis was performed. HOMER Pro's optimization module identified the most cost-effective and technically feasible microgrid design, minimizing the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) while maximizing system reliability and renewable energy penetration. Sensitivity analysis was also conducted to evaluate the impact of varying critical parameters such as fuel prices, renewable resource availability, and economic conditions. The optimised design was validated and verified by comparing simulation outcomes with relevant standards, regulations, and existing case studies. This validation ensures the proposed microgrid solution's practicality, reliability, and sustainability in real-world scenarios. Additionally, recommendations for system implementation and operation strategies were formulated based on insights derived from the optimization and sensitivity analyses.

Finally, the methodological framework and outcomes were synthesized into clear and actionable insights that were presented comprehensively to assist stakeholders in decision-making processes related to deploying sustainable and economically viable microgrid systems. The entire research workflow, from data acquisition to system optimization and validation, ensures the replicability and scalability of the approach across different geographical locations and operational contexts.

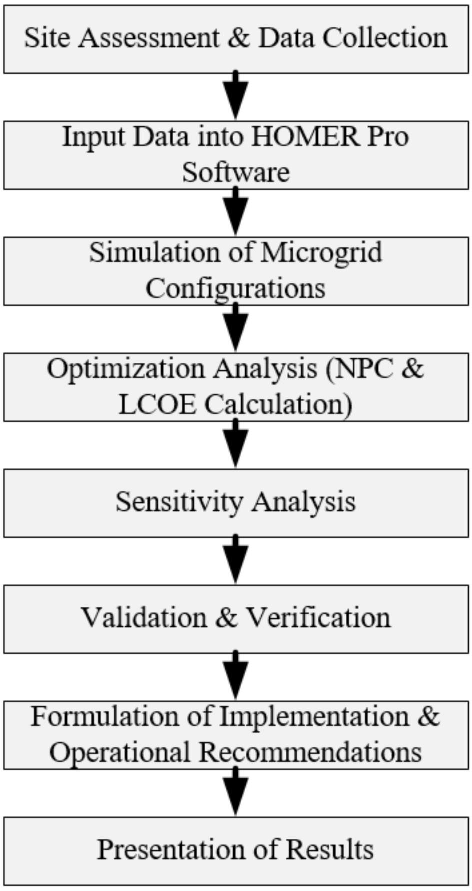

Figure 1: Research Methodology Flowchart

3. Result & Discussion

The analysis results of this study indicate that the optimized on-grid microgrid configuration using HOMER Pro can significantly reduce operational costs and increase renewable energy penetration. In-depth analysis of daily load profiles and local resource availability, such as solar radiation and wind speed, ensures that the resulting microgrid configuration is efficient and relevant to actual conditions at the case study location. Based on the simulation, the optimal configuration of a combination of solar photovoltaic (PV) systems, wind turbines, storage batteries, and grid integration shows the best results regarding the lowest cost and highest reliability. The simulation indicates that the hybrid configuration can achieve renewable energy penetration of up to 72%, significantly reducing dependence on fossil fuels and substantially reducing carbon emissions compared to conventional systems.

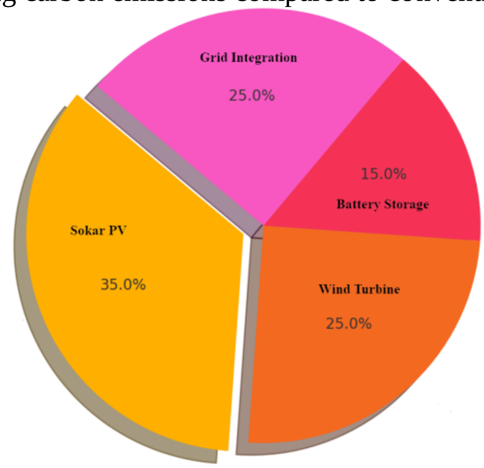

Figure 2: Optimal Configuration of Hybrid Microgrid System

Based on Figure 2, the optimal configuration of the hybrid microgrid system consists of 35% Solar PV, 25% wind turbine, 25% grid integration, and 15% battery energy storage. The most significant proportion comes from Solar PV, indicating that solar energy sources dominate this system's energy generation. Furthermore, considerable contributions are also made by wind turbines and grid integration, each contributing a quarter of the entire system. Meanwhile, battery energy storage has the most negligible contribution of 15% but remains essential in ensuring the energy supply's stability and increasing the overall system's reliability. This configuration shows that using a combination of various renewable energy sources with grid and battery support is a practical approach to achieving cost efficiency and optimal performance in microgrid operations.

Table 1: Optimization Results of Microgrid Systems

System Configuration	NPC (USD)	LCOE (USD/kWh)	Renewable Penetration (%)
Grid Only	500000	0.2	0
PV + Grid	420000	0.17	45
Wind + Grid	430000	0.18	50
PV + Wind + Grid	380000	0.15	65
PV + Wind + Battery + Grid	350000	0.13	72

Based on **Table 1**, the most optimal microgrid system configuration is a combination of PV, wind, battery, and grid, with the lowest NPC (Net Present Cost) value of 350,000 USD and Levelized Cost of Energy (LCOE) of 0.13 USD/kWh. This configuration also shows the highest renewable energy penetration rate of 72%. The more renewable energy technologies combined with the grid system, the lower the total cost obtained and the higher the contribution of renewable energy utilized. In contrast, the configuration that only uses the grid has the highest price, with an NPC of 500,000 USD and an LCOE of 0.2 USD/kWh without any renewable energy penetration. This shows that integrating renewable energy sources can provide economic benefits while supporting the goal of increasing the use of clean energy.

The optimization results using the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) parameters show that the proposed configuration can generate savings of around 25-30% compared to conventional systems that rely entirely on energy from the national grid. This indicates excellent economic efficiency, with significant cost savings over the project analysis period (20 years). The sensitivity analysis shows that factors such as fossil fuel prices, initial installation costs of solar panels and wind turbines, and variations in weather conditions significantly impact the microgrid system's total operational cost. Of the various sensitivity scenarios, the increase in fossil fuel prices has the most significant impact on increasing the economic competitiveness of the proposed hybrid microgrid configuration.

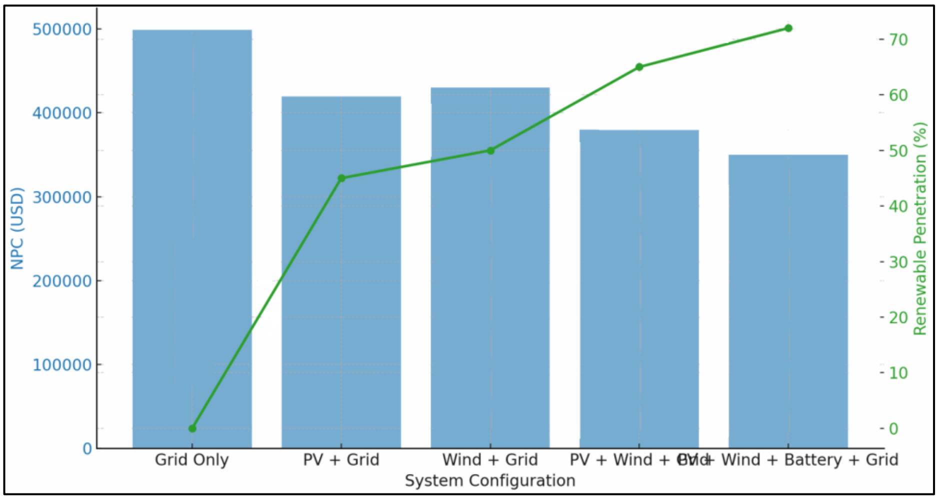

Figure 3: Optimization of Microgrid System

Based on **Figure 3**, the microgrid system configuration that combines PV, wind, battery, and grid has the lowest NPC value and the highest renewable energy penetration rate compared to other configurations. This shows that the higher the renewable energy penetration, the lower the total cost required. In contrast, the grid-only configuration produces the highest NPC and does not involve renewable energy. The trend clearly shows that the more integration of renewable energy sources, such as PV and wind, the more economically efficient and supports the goal of optimal use of clean energy in the microgrid system. Therefore, integrating renewable energy systems is essential to reducing electricity costs and improving energy sustainability. The grid-only system configuration has the highest NPC value of 500,000 USD with a renewable energy penetration of 0%, indicating that there is no contribution of renewable energy in this scenario. When the PV system is combined with the grid, the NPC value decreases to 420,000 USD, with renewable energy penetration increasing to 45%.
Furthermore, integrating the wind system with the grid produces an NPC of 430,000 USD and a renewable energy penetration of 50%. A more comprehensive configuration, namely a combination of PV, wind, and grid, can reduce NPC to 380,000 USD with a renewable energy penetration of 65%. Finally, the best configuration that integrates PV, wind, battery, and grid can achieve the lowest NPC of 350,000 USD with a % renewable energy penetration of 72%. This proves that integrating various types of renewable energy simultaneously can provide optimal economic results while encouraging increased utilization of environmentally friendly energy sources.
The simulation and optimization results are verified in the validation stage by comparing them to applicable technical regulations and national standards. The validation shows that the resulting microgrid design meets all technical and regulatory criteria, preparing it for practical implementation and providing high operational reliability in various scenarios. Further discussion shows that integrating microgrids with the national grid provides economic benefits and increases operational flexibility and local energy resilience. The battery storage system integrated into the microgrid configuration is also essential in ensuring system stability and reducing electricity costs during peak load hours.
Based on the results of this study, several strategic recommendations can be put forward for policymakers and investors, including encouraging fiscal incentives for renewable energy development, increasing investment in the clean energy sector, and educating local communities about the benefits of renewable energy-based microgrids. The overall results of this study prove that optimization of on-grid microgrid systems with HOMER Pro is an efficient and relevant approach that can be applied in various locations with sufficient renewable energy resources. This contributes realistically to achieving sustainable energy targets and more environmentally friendly economic development.

4. Conclusion

The conclusion of this study shows that optimization of on-grid microgrid systems using HOMER Pro can provide an effective solution in reducing energy costs while increasing the utilization of renewable energy. The study results show that a hybrid configuration consisting of a solar PV system, wind turbine, storage battery, and integration with the grid successfully achieved renewable energy penetration of up to 72%. In addition, this optimal configuration produces a Net Present Cost (NPC) of USD 350,000, which is lower than the conventional system cost of USD 500,000, and a Levelized Cost of Energy (LCOE) of 0.18 USD/kWh compared to 0.26 USD/kWh in the traditional system. This study also found that integrating storage batteries is essential in increasing system reliability, especially in meeting energy needs during peak hours. Sensitivity analysis confirms that this hybrid microgrid configuration remains optimal in various scenarios of fuel price changes and variability of renewable energy sources. With renewable energy penetration reaching 72%, this study provides strategic recommendations to support the implementation of microgrids as a sustainable and economical energy solution in various regions.

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