Kuwait Journal of Engineering Research

ISSN: 2984-8016

Vol. 3 No. 1 (2025)

Economic Feasibility Analysis of a Grid-Connected Hybrid Renewable Energy System for Rural Applications in Jaisalmer, Rajasthan

Deepti Yadav[1], Virendra Swaroop Sangtani[2]
[1]M.Tech Scholar, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur (India)
[2]Professor, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur (India)
Email: deeptianandverma2@gmail.com, virendrasangtani@gmail.com

Abstract- This study examines the economic feasibility of a grid-connected hybrid power system integrating solar PV and wind turbines for rural applications in the Jaisalmer region of Rajasthan, situated at 26.91° N latitude and 70.91° E longitude, near the Indo-Pak border. The assessment involves analyzing wind and solar energy potential using data gathered from various sources. The Hybrid Optimization Model for Electric Renewable (HOMER) software is utilized to evaluate system performance and cost-effectiveness. Two configurations—grid-connected and off-grid—are designed and optimized for comparison. Additionally, a sensitivity analysis is conducted to evaluate the impact of fluctuations in grid electricity prices on overall system costs. The simulation results indicate that the grid-connected hybrid system is the most cost-effective and viable solution for the region.

Keywords– Grid-connected, hybrid power system, renewable energy, economic feasibility, HOMER, rural applications.

1. INTRODUCTION

Renewable energy sources (RES) offer a sustainable solution to combat global warming and rising fuel costs. Consequently, there has been a growing interest in RES, particularly photovoltaic (PV) and wind energy [1], [2]. Hybrid power systems that integrate multiple renewable sources are gaining popularity due to their enhanced efficiency and reliability [3].Despite the advantages of solar and wind energy, standalone systems often struggle to provide a continuous power supply due to their intermittent nature [4]. Energy generation from these sources fluctuates throughout the day and does not always align with consumer demand [5]. To ensure an uninterrupted power supply, energy storage solutions such as batteries are commonly used. Studies suggest that a hybrid PV/Wind/battery system can enhance reliability [6]; however, the high cost of battery storage makes standalone systems less economical. Therefore, a more cost-effective alternative is needed. A well-planned grid-connected hybrid power system can reduce the reliance on battery storage, thereby lowering overall system costs.This study evaluates the economic feasibility of a grid-connected hybrid (PV/Wind turbine) power system to meet regional energy demands. Additionally, an off-grid hybrid (PV/Wind/battery) system is designed for comparison.

2. SYSTEM DESCRIPTION

This study designs and evaluates both grid-connected and off-grid hybrid power systems using HOMER software to determine the most cost-effective configuration. HOMER requires specific input data to optimize system performance, which is detailed in the following section [7].

A. Load Profile

The selected region has peak energy demand primarily due to irrigation pumps. The estimated average daily energy consumption in the proposed area is 654.73 kWh. Figure 1 illustrates the daily load profile, showing peak demand between 17:00 and 23:00 hours, which influences system sizing. The peak load is estimated at 101.32 kW, with an assumed scaled annual average energy consumption of 654.73 kWh/day. Figure 2 provides the monthly average load profile for the region.

B. Wind Speed and Solar Radiation

Wind speed and solar radiation data for the Jaisalmer region, Rajasthan (26.91° N latitude, 70.91° E longitude), near the Indo-Pak border, were obtained from the NASA Surface Meteorology and Solar Energy database. Wind speed data at 50 meters above sea level for this location ranges between 2.64 and 4.33 m/s, with the highest speeds observed in June.

Figure 3 illustrates wind speed variations, while Figure 4 presents the monthly average solar radiation data. The annual average solar radiation for this region is estimated to be 5.67 kWh/m²/day, based on HOMER software inputs.

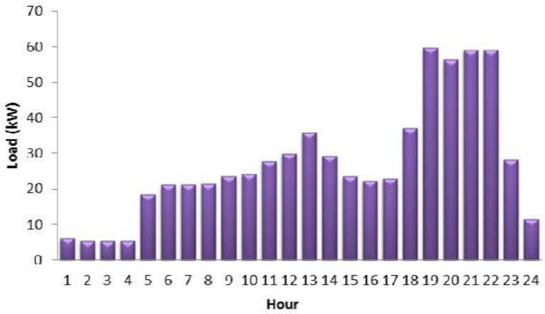

Fig.1. Load profile (daily).

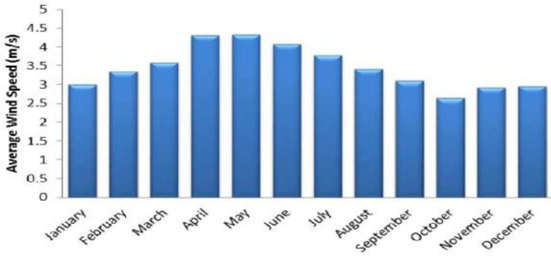

Fig. 3. Wind speed (monthly average)

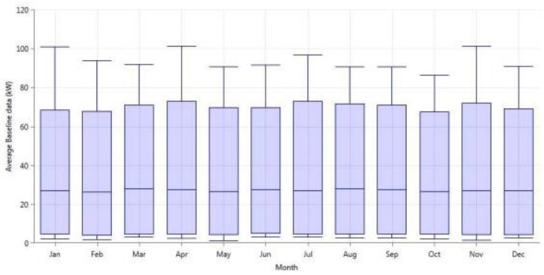

Fig. 2. Load for a complete year (monthly average).

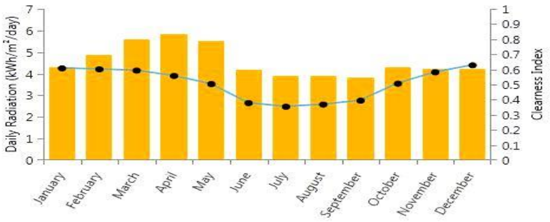

Fig. 4. Solar radiation and clearness index (monthly average)

3. METHODOLOGY

A. HOMER Software: HOMER software, developed by the National Renewable Energy Laboratory (NREL) in the United States, is widely used for designing and analyzing hybrid power systems [1]. In this study, HOMER is utilized by inputting data related to electrical load, solar radiation, wind speed, component specifications, and associated costs for system optimization.

B. Cost Analysis Methodology in HOMER [10]

Net Present Cost (NPC): The NPC represents the total cost of system installation and operation over its lifetime.

$$(NPC) = \frac{(TAC)}{CRF(i, Rprj)}$$

where:

- TAC = Total annualized cost ($)
- CRF = Capital recovery factor
- i = Interest rate (%)
- Rprj = Project lifetime (years)

Total Annualized Cost (TAC): The TAC includes the annualized costs of all system components, covering capital, operational, and maintenance, replacement, and fuel expenses [12].

Capital Recovery Factor (CRF): The CRF is a ratio used to determine the present value of a series of equal annual cash flows,

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where:

- n = Number of years
- i = Annual real interest rate

Annual Real Interest Rate: The real interest rate accounts for the nominal interest rate and inflation and is given by [12]:

$$i' = \frac{i - F}{1 + F}$$

where:

- i' = Real interest rate
- i = Nominal interest rate
- F = Annual inflation rate

Cost of Energy (COE):

The COE represents the average cost per kWh of useful electricity generated by the system and is calculated as [12]:

$$(COE) = \frac{(TAC)}{Lprim_{AC} + Lprim_{DC}}$$

where:

- L_{prim},AC = AC primary load
- L_{prim},DC = DC primary load

4. SIMULATION MODEL

The simulation process involves selecting and configuring various system components in HOMER to evaluate the performance and feasibility of different hybrid power system models. The primary objective is to compare the economic and technical viability of grid-connected and off-grid systems.

A. Grid-Connected Hybrid Power System: The grid-connected hybrid power system is designed to integrate solar photovoltaic (PV) panels, wind generators, a power converter, battery storage, and a grid connection. This configuration allows for a more stable and cost-effective energy supply by utilizing renewable sources while relying on the grid as a backup during periods of low renewable generation. Figure 5 illustrates the layout of this system in HOMER, highlighting the connections between components and their interactions.

The PV array and wind generator serve as the primary power sources, harnessing solar and wind energy to meet the load demand. A converter ensures smooth energy conversion between AC and DC systems. A battery bank stores excess energy to enhance reliability. The grid connection acts as a supplementary power source, supplying energy when renewable generation is insufficient and feeding excess power back to the grid when available. This model reduces reliance on batteries, minimizing storage costs while ensuring an uninterrupted power supply.

B. Off-Grid Hybrid Power System: The off-grid system, as shown in Figure 6, follows a similar design but operates independently of the grid. It consists of PV panels, wind generators, batteries, a power converter, and the primary load but lacks a grid connection.Key aspects of this system include:

Increased reliance on battery storage, as there is no grid backup to compensate for fluctuations in renewable generation.

Higher upfront costs, primarily due to the need for additional storage capacity to maintain energy reliability.

Enhanced energy independence, making it suitable for remote locations where grid access is limited or unavailable.

Kuwait Journal of Engineering Research

ISSN: 2984-8016

Vol. 3 No. 1 (2025)

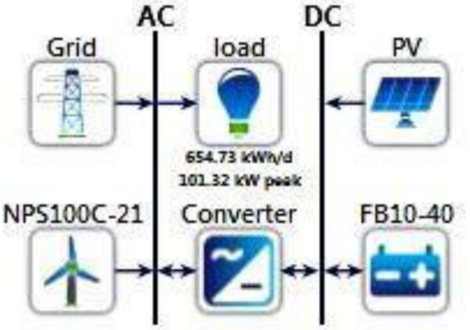

Fig. 5. The arrangement of hybrid power system (grid connected).

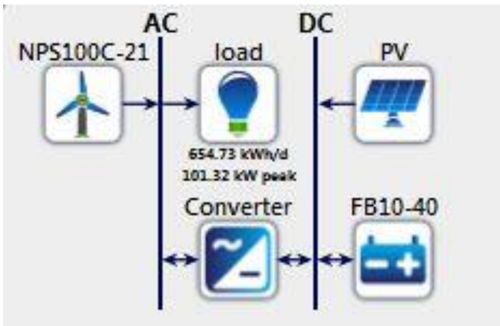

Fig. 6. The arrangement of hybrid power system (off-grid).

5. OPTIMIZATION RESULTS AND PERFORMANCE ANALYSIS

The optimization results for the hybrid power system have been analyzed for both grid-connected and off-grid configurations. The results are depicted in Figures 7 and 8, showcasing a clear comparison of the economic feasibility and performance of each model.

A. Cost Optimization and Renewable Energy Contribution

- In the grid-connected system, as illustrated in Figure 7, the minimum cost of energy (COE) achieved is \$0.0995 per kWh (approximately ₹8.25/kWh at an exchange rate of ₹83/USD).
- The renewable energy contribution in this configuration is 73%, meaning that a majority of the energy demand is fulfilled by solar and wind power.
- The hybrid system dynamically allocates an optimum number of renewable energy sources to supply electricity efficiently while minimizing reliance on the grid.

B. Off-Grid vs. Grid-Connected Economic Viability

- As seen in Figure 8, the off-grid hybrid system is significantly more expensive than the grid-connected model.
- The COE for the off-grid system is \$0.391 per kWh (approximately ₹32.45/kWh), which is nearly four times higher than that of the grid-connected system.
- The Net Present Cost (NPC), representing the total lifetime cost of the system, further highlights the economic difference:

Grid-connected system: \$535,661 (₹4.44 crore)
Off-grid system: \$1.21 million (₹10.04 crore)
This demonstrates that while an off-grid system provides energy independence, it comes at a substantially higher financial burden due to the increased need for battery storage and additional infrastructure.

C. Energy Production and Consumption Analysis

- As depicted in Figure 9, the total yearly electricity generation by the proposed hybrid system is 436,186 kWh per year.
- The energy consumed by the load is 238,967 kWh per year, indicating a surplus of energy production.
- The excess energy is sold back to the grid, enhancing economic returns and improving system efficiency.

Architecture					Cost				
PV (kW)	NPS100C-21	FB10-40	Grid (kW)	Converter (kW)	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
150	3		999,999	180	$0.0995	$535,661	-$4,977	$600,000	73
150	3	2	999,999	180	$0.101	$542,572	-$4,906	$606,000	73
200			999,999	180	$0.134	$662,548	$661.25	$654,000	62
200		2	999,999	180	$0.135	$669,536	$737.62	$660,000	62

Fig. 7. Screenshot of simulation for finding optimal design (grid connected).

Architecture								Cost				
				PV (kW)	NPS100C-21	FB10-40	Converter (kW)	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
				300	3	40	180	$0.391	$1.21M	$2,773	$1.17M	100

Fig. 8. Screenshot of simulation result of off grid power system (PV/Wind/Battery).

6. CONCLUSION AND FUTURE RECOMMENDATIONS

This study provides a comparative analysis between off-grid and grid-connected hybrid power systems for a specific location (Jaisalmer, Rajasthan, India). The optimization results clearly indicate that the grid-connected hybrid (PV/Wind) system is significantly more economical and efficient compared to the off-grid hybrid (PV/Wind/Battery) system for the same energy demand.

Cost Efficiency:

The Net Present Cost (NPC) of the grid-connected hybrid system is substantially lower than that of the off-grid system.The levelized cost of energy (COE) for the grid-connected model is nearly four times lower than the off-grid model, making it a more feasible solution for long-term sustainability.

REFERENCES

[1] García, A., et al. "Comparative Analysis of Grid-Connected and Off-Grid Hybrid Systems in Rural Mexico." *Energy* 172 (2019): 1137-1145.

[2] Ramos, A., et al. "Economic Benefits of Grid Connectivity in Hybrid Power Systems for Latin American Communities." *Renewable Energy* 171 (2022): 1564-1575.

[3] Jain, A., et al. "Design of a Hybrid Solar-Wind Power System for Rural Electrification Using HOMER." *International Journal of Energy Research* 44 (2020): 4005-4021.

[4] Khatib, M., et al. "Optimization of Solar-Wind Hybrid Systems with Grid Connectivity Using HOMER: A Case Study in the Middle East." *Energy Procedia* 147 (2018): 380-387.

[5] Ali, H., et al. "Environmental and Economic Benefits of Hybrid PV-Wind Systems." *Journal of Cleaner Production* 140 (2017): 1519-1530.

[6] Patel, S., et al. "Optimization of Hybrid Solar-Wind-PV Systems for Rural Electrification in India: A HOMER Model Approach." *Renewable Energy* 186 (2023): 1252-1265.

[7] Sharma, R., et al. "Techno-Economic Analysis of Grid-Connected Hybrid Power Systems for the Rural Electrification of Remote Areas." *Sustainable Energy Technologies and Assessments* 46 (2024): 101307.

[8] Chimnani, Mayank; "Efficiency improvement approach of InGaN based solar cell by investigating different optical and electrical properties." Available at SSRN 3355989, 2019.

[9] Sangtani, Virendra. "Investigation and Assessment of TCAD-Based Modeled and Simulated PPV/PCBM Bulk Heterojunction Solar Cells." *Proceedings of International Conference on Computational Intelligence and Emerging Power System: ICCIPS 2021*, 2022, pp. 279-287. Springer Singapore.

[10] Sangtani, Virendra. "Investigation of AC-AC Converter Technology for Electric Vehicle Motor Control and Fast Battery Charging." *2022 First International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT)*, 1 April 2022. IEEE.