Journal of Information Systems Engineering and Management
2025, 10(13s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Optimized Design of Hybrid Solar Power Systems in Jhansi, India: Enhancing Efficiency

Garima Singh[1], Bharat Raj Singh[2]
[1] *Research Scholar, Babu Banarasi Das Northern India Institute of Technology, Department of Mechanical Engineering, Uttar Pradesh, India*
[2] *Ph.D, School of Management Sciences, Lucknow, Director General (Technical), Uttar Pradesh, India*

ARTICLE INFO

Received: 01 Dec 2024

Revised: 15 Jan 2025

Accepted: 29 Jan 2025

ABSTRACT

Introduction: This study focuses on designing and optimizing a hybrid solar power generation system tailored to the energy challenges of Jhansi, India. With the goal of enhancing energy efficiency, integrating solar power with complementary renewable sources emerges as a pivotal strategy. Employing the advanced capabilities of HOMER software, the research explores various system configurations to identify the most efficient setup for Jhansi's unique requirements. The findings provide valuable insights for policymakers, researchers, and industry stakeholders, offering guidance in navigating the complexities of the energy transition. These insights emphasize the transformative potential of hybrid solar power systems, demonstrating how advanced optimization tools like HOMER can drive sustainable energy solutions in India and globally. The study highlights the significant benefits of hybrid systems, such as PV-Biomass and Solar-Wind, in stabilizing energy systems, mitigating climate change, and fostering economic growth. By addressing Jhansi's energy needs, the research underscores the importance of renewable energy integration in achieving sustainable development. The results point to substantial improvements in energy generation and utilization, showcasing the potential for hybrid systems to overcome energy challenges while contributing to a more sustainable and resilient energy future in the region and beyond.

Keywords: Renewable energy, Sustainability India, Power Generation, Power Cycle, Energy Storage

INTRODUCTION

The growing demand for electricity, coupled with the need for sustainable energy solutions, has led to increased interest in solar power generation systems worldwide. In regions like Jhansi, India, where energy access and reliability are significant concerns, the development of efficient renewable energy systems is crucial. Hybrid solar power generation, which integrates solar energy with other renewable sources, offers a promising solution to address these challenges. By seamlessly integrating solar energy with other renewable sources, hybrid systems offer a multifaceted solution that not only enhances energy production but also addresses issues of intermittency and reliability inherent in standalone solar or wind setups. As articulated by Jyoti Gulia et al**. [1],** in their seminal work on Wind-Solar Hybrid projects in India, the synergy between wind and solar resources holds immense promise for bolstering the plant load factor (PLF) of hybrid installations. Unlike standalone solar or wind plants, which typically exhibit PLFs ranging from 20% to 35%, hybrid projects boast PLFs that can soar to around 50%. This substantial increase is attributed to the complementary nature of solar and wind resources, wherein the intermittent nature of one is offset by the consistent availability of the other **(Figure 1)**.

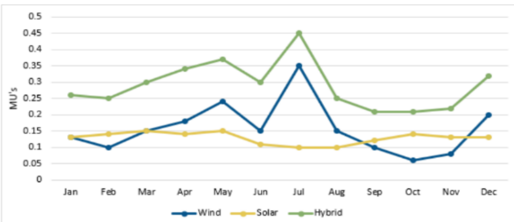


Figure 1. India's monthly Wind, Solar and Hybrid Generation Profile

In the Indian context, the National Wind Solar Policy 2018 serves as a guiding beacon, delineating a strategic roadmap for the integration of wind and solar resources into the nation's energy portfolio. States are urged to align their renewable energy targets with this policy framework, thereby earmarking a proportion of their objectives for wind-solar hybrid (WSH) projects. Moreover, incentivizing measures such as waivers, incentives, and optional collocation criteria are recommended to stimulate market growth and incentivize private sector participation in this burgeoning sector. Against this backdrop, this study endeavors to contribute to the burgeoning discourse on hybrid solar power generation by focusing on the specific energy landscape of Jhansi. Leveraging state-of-the-art optimization tools such as HOMER software, the research seeks to design and optimize a hybrid solar power generation system tailored to the unique requirements and challenges of the region. The study aims to pave the way for a sustainable energy future in Jhansi, one that aligns with broader national and global imperatives for renewable energy adoption and climate mitigation. Ultimately, this study aims to design and optimize a hybrid solar power generation system in Jhansi, leveraging HOMER software to enhance efficiency and reliability.

LITERATURE REVIEW

Previous studies have highlighted the potential of hybrid solar power generation systems to improve energy efficiency and reliability in various regions. In India, where solar irradiance is abundant, several research efforts have focused on optimizing solar power systems for specific locations. HOMER, a widely used optimization tool, has been instrumental in designing and analyzing hybrid renewable energy systems. Research conducted by Gupta et al. **[2]** demonstrated the effectiveness of HOMER in optimizing hybrid solar-wind systems in rural areas of India, showcasing significant improvements in energy output and cost-effectiveness. Similarly, studies by Singh et al. **[3]** emphasized the importance of integrating multiple renewable energy sources to enhance system performance and reliability. Building upon these findings, this study aims to extend the application of HOMER to design and optimize a hybrid solar power generation system tailored to the energy needs of Jhansi.

Current Status of Hybrid Solar Power Generation in India

Harpreet Kaur et. al **[4]** analyzed hybrid solar biomass power plant for generation of electric power. Renewable energy, derived from sources like the sun and wind, is crucial for electricity, heating, transport, and rural energy. Its widespread use can stabilize energy systems, mitigate climate change, and offer economic advantages. Hybrid systems, such as PV-Biomass, address the intermittency of solar and wind power.Pranav Kadam et.al **[5]** discussed hybrid power generation through combined solar-wind power system. The project aims to create a hybrid power generation system that connects to the grid, utilizing both solar and wind energy sources, with the simulation and development done using MATLAB/Simulink software. the photovoltaic (PV) model is simulated under various radiation and temperature scenarios, and its output is monitored. The hybrid model, combining solar and wind energy, is simulated, and the results are analyzed using MATLAB.

Hybrid Solar Power Generation Approach

Nishant Jha et.al **[6]**, analyzed energy-efficient hybrid power system model based on solar and wind energy for integrated grids. The findings of research paper suggest that incorporating hybrid PV-wind power generation units can reduce costs by 10%–20% compared to existing systems. This study promotes the adoption of hybrid systems in India and globally to enhance the sustainability of electricity production. These systems can offer reliable power to rural areas, support community grid maintenance, and stimulate economic growth. Overall, the widespread use of hybrid systems will boost renewable energy adoption for electricity generation worldwide, aiding in addressing current environmental challenges. Alok Das et.al **[7]**, presented a comprehensive review of wind–solar hybrid energy policies in India: Barriers and Recommendations", this article examines the current global renewable energy policies and discusses the evolution of renewable energy policies in India since the 1990s, highlighting the measures taken to promote renewable energy-based power generation. While onshore wind energy projects are operational in India, offshore wind projects are in their early stages and have not been fully explored yet. Faizan A.Khan et.al **[8]**, optimized sizing of SPV/Wind hybrid renewable energy system: A techno-economic and social perspective. The study analysed seven feasible combinations of different resources to determine the optimal design parameters. Through a multi-criteria analysis, the combination of solar photovoltaic, wind, diesel generator, and battery storage were identified as the best for ensuring a consistent power supply. The net present cost was calculated as $0.179, with a cost of energy of $31,439. Sensitivity analysis was conducted for macro-economic factors and component costs to identify opportunities for improvement. Additionally, the proposed system underwent robustness checks to ensure its technical and commercial viability in meeting consumer demand.

Role of HOMR software in Hybrid Solar Power Generation

Sarang Kapoor et. al **[9]**, discussed techno-economic analysis by homer-pro approach of solar on-grid system for Fatehpur-Village, India. HOMER Pro provides optimized results for a selected site, considering factors such as total present cost (NPC), the least cost of energy (LCOE), and operating costs. The simulation results yielded a levelized cost of energy (LCOE) of 1.77 Rs/kWh, which is significantly lower than the grid power price of 5.6 Rs/kWh, with a total NPC of 9,291,770.00 Rs. The main criteria used in this software package are NPC and LCOE to determine the best outcomes for a given site. Vendoti Suresh et. al **[10],** discussed modelling and optimization of an off-grid hybrid renewable energy system for electrification in a rural area. This project focuses on electrifying three villages in the Kollegal block of Chamarajanagar district, Karnataka State, India, using an off-grid hybrid renewable energy system. The goal is to optimize the system's control, sizing, and component selection to provide a cost-effective power solution for the community. The main objective is to reduce the Total System Net Present Cost (TNPC), Cost of Energy (COE), unmet load, and CO_2 emissions using Genetic Algorithm (GA) and HOMER Pro Software.Ashkan Toopshekan et.al **[11]**, presented a technical, economic, and performance analysis of a hybrid energy system using a novel dispatch strategy. This study examines the effectiveness of an on-grid photovoltaic (PV)/wind turbine (WT)/diesel/battery system for a residential area in Tehran, Iran. The system is designed to meet a daily load demand of 112.7 kWh, with a peak load demand of 26.66 kW. A new dispatch strategy is developed using MATLAB Link in HOMER software, which considers 24-hour foresight for power grid outages, future electrical demand, solar irradiation, and wind speed.S. Suriadi et. al **[12]**, presented the optimization of hybrid power generator system (PV-Wind turbine) using Homer software. This research aimed to assess the potential of a hybrid power generation system combining photovoltaic (PV) and wind turbine technologies, and to optimize the electric energy requirements using the Hybrid Optimization Model for Electric Renewable (HOMER) software. The results validate the study as a valuable reference for governments seeking to build power generation systems using renewable energy sources. Linta Khalil et.al **[13]** evaluated a hybrid system and designed for the Baluchistan's Seashore in which the designing of grid deals with wind, solar installation and converters installation which decreases amount payable to grid. They estimated power generation, pollutant gases emissions, net present cost and average electrical production cost using HOMER Pro software. The results are sorted in such a way that the proposed hybrid system design is the most economical in terms of operating cost, net present cost and gases emissions

METHODOLOGY

The methodology involves several steps, beginning with data collection on solar irradiance patterns, energy demand, and available renewable resources in the Jhansi region [**14-15**]. Using HOMER software [**16**], various system configurations comprising solar panels, battery storage, and other renewable energy sources like: Wind Power generation are modeled and simulated. The optimization process includes the evaluation of different parameters such as system size, component specifications, and operating strategies to maximize efficiency and minimize costs. Sensitivity analysis is conducted to assess the impact of different factors on system performance. The most promising configurations are identified based on predefined criteria, and their feasibility and effectiveness are evaluated.

Area Selection

Situated within the heartland of Bundelkhand, Jhansi is situated at the banks of the Pahuj River, nestled in the southernmost reaches of Uttar Pradesh, India. At the precise geographical coordinates of 25.4333° N latitude and 78.5833° E longitude, this city faces a unique blend of geographical charm and climatic diversity. With an average elevation standing proudly at 284 meters (935 feet) above sea level, Jhansi commands a view from the plateau of central India, where rocky terrain and hidden mineral reserves define the landscape. The city's natural topography unveils itself with a subtle slope towards the north, as it stands guard on the southwestern frontier of the expansive Tarai plains of Uttar Pradesh.

However, as one traverses towards the southern horizon, the elevation gracefully ascends, offering a panoramic vista of the surrounding terrain. Amidst this geographical splendor, Jhansi bears witness to climatic extremities that paint its seasons with vivid hues. As the sun blazes its fiery path across the summer skies, temperatures in Jhansi soar to staggering heights, often reaching between 45 to 49 °C (113.0 to 120.2 °F), enveloping the city in a blanket of heat. Conversely, when winter unfurls its icy embrace, the mercury plummets to chilling lows, with temperatures dropping as low as 0 to 1 °C (32.0 to 33.8 °F), as documented during the winter of 2011. Thus, Jhansi's geographical tapestry narrates climatic contrasts that add depth to study for hybrid solar power generation.

Energy Demand Estimation

The research project focuses on the increasing demand for energy in Jhansi city, considering consumption for domestic, commercial, industry, public water work, street light and other purposes. They collected detailed data on how energy is used in places like hospitals, schools, shops, streetlights, and more. In the month of January 2019-2020 fiscal year, Jhansi's total energy demand was 365.74 in lakh units which was shown in **Table 1** and **Figure 2**. The project also uses software called HOMER to analyse the city's energy usage patterns throughout the year, include ng daily and seasonal variations [**14-15**].

A comprehensive overview of the yearly, seasonal, and daily load profiles within the study location is offered by **Figure 3, Figure 4, Figure 5, Figure 6** and **Figure 7**, which were generated using HOMER SOFTWARE [**16**].

Table 1. Sector-wise Energy Consumption by Jhansi City in 2019-20 in the Month of January

Sector	**Energy Use (in Lakhs)**
Consumption of Electricity -Domestic purpose	184.58
Consumption of Electricity-Commercial purpose	31.05
Consumption of Electricity-Industry purpose	80.1
Consumption of Electricity-Public Water Work & Street Light	61.91
Consumption of Electricity-Others	8.1
Consumption of Electricity-Total Consumption	365.74

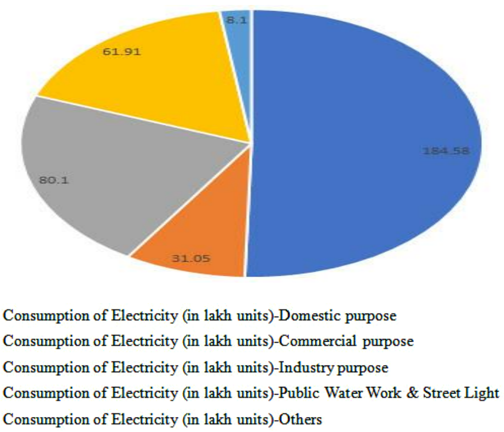


Figure 2. Sector-wise Energy Consumption by Jhansi City in 2019-20 in the Month of January

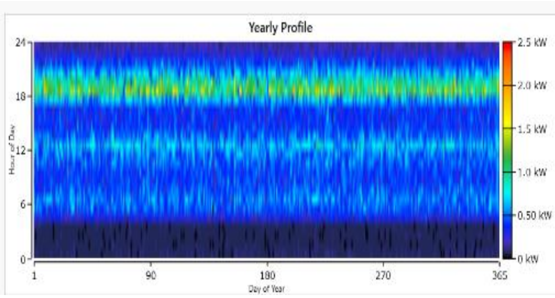


Figure 3. Yearly Load Profile within the Study of Jhansi

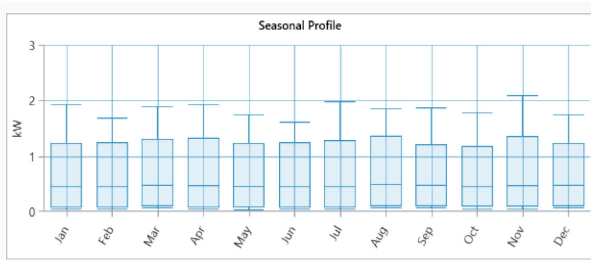


Figure 4. Seasonal Load Profile within the Study

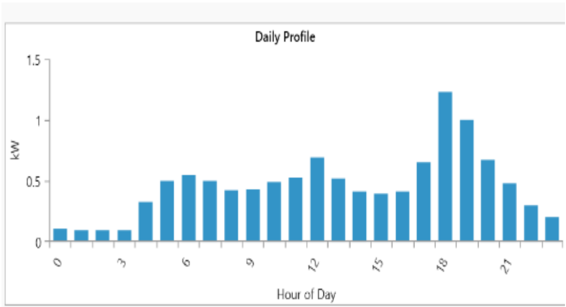


Figure 5. Daily Load Profile within the Study

Solar Resources

Figure 6, generated using HOMER SOFTWARE, displays the annual daily solar irradiation available within the study location. The highest solar irradiation, 6.320 kWh/m²/day, was recorded in April, while the lowest, 3.840 kWh/m²/day, was recorded in December.

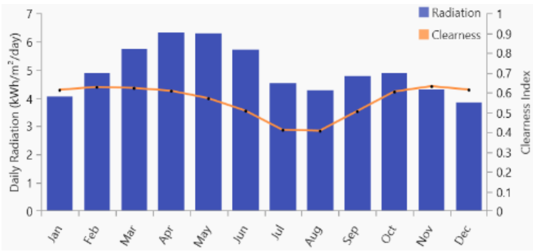


Figure 6. Annual Solar Radiation within the Study

Wind Resources

Figure 7, generated using HOMER SOFTWARE, displays the monthly average wind speed data annual available within the study location. The highest average wind speed, 5.830 m/s, was recorded in June, while the lowest, 3.27m/s were recorded in November.

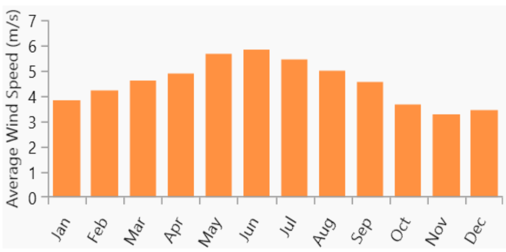


Figure 7. Annual Monthly Wind Speed within the Study

STATISTICAL ANALYIS

Mathematical Modelling of solar and Wind Panel

Solar PV component: The Generic flat plate PV with 36 kW capacities is selected here (HOMER SOFTWARE). The output power of PV system is assessed by the expression (1) and (2).

$$P_S = In(t) * A_S * Eff(pv) \qquad (1)$$

As, P_S indicates power obtained from solar panels, In (t) is isolation at time t in kw/m^2, A_S shows single PV panel area and Eff (pv) shows overall efficiency of PV panels

For representation of overall efficiency,

$$Eff(pv) = H*PR \qquad (2)$$

As, Eff (pv) indicates overall efficiency of pv panels, PR is performance ratio and H is average solar radiation on panels/year [13]

Battery Storage: The Generic 1kWh Li-Ion [ASM] battery is selected here. **Table 2** represent the properties of advanced storage battery model (HOMER SOFTWARE) [16].

Table 2. Properties of Advanced Battery Storage Model

Nominal Voltage (V)	3.7
Nominal Capacity (kWh)	1.02
Maximum Capacity (Ah)	276
Other round-trip losses (%)	8
Fixed bulk temperature (C)	20

System converter: System converter is employed as a power conditioning unit to facilitate power flow between DC and AC buses and vice versa. In the proposed project, system converter plays a crucial role in the Solar-Wind hybrid system, efficiently converting DC to AC (inversion) with 95% efficiency and AC to DC (rectification) with 95% efficiency.

Wind Turbine Generating System: The optimized HSPV model incorporates a 'XANT M-21 [100KW] wind turbine having hub height 31.30 mt. The power produced by the wind turbine is stated by expression (3) in terms of air density, swept area and speed of wind [13].

$$P_W = \frac{1}{2} \rho A_W V^3 \qquad (3)$$

As, P_W indicates power obtained from wind turbine, ρ is air density, A_W is swept area and V is the speed of wind.

The total power production of a Solar-Wind hybrid system is the sum of the power generated by solar panels and wind turbines. Mathematical expression (4) indicates power generated by solar-wind hybrid system.

$$P_T = N_W*P_W + N_S*P_S \qquad (4)$$

As, P_T represents total power generated of the system. N_W is number of wind turbine and N_S is number of solar panels [13].

Tariff: Simple tariff is used in the proposed HSPV system. Energy charges in rupees/kWh and fixed charges in rupees/month are considered [14].

CRITERIA OF EVALUATION

Net Present Cost: In economic analysis, the Net Present Cost (NPC) is a key parameter used to evaluate the cost-effectiveness of a project over its lifetime. It is calculated by summing the initial cost, replacement cost, and the present value of the lifetime operation and maintenance costs. Mathematically, the NPC can be expressed as expression (5),

$$\text{Net Present Cost}=\frac{\text{Total Annualized Cost (\$/year)}}{\text{Capital Recovery Factor (Iy,t)}} \quad (5)$$

As, t is the life-time period of project, I_y is the annual real interest rate $(%) that is calculated in terms of annual inflation rate (f), and nominal interest rate (I_n) by expression (6).

$$I_y=(I_n-f) / (1+f) \quad (6)$$

The Capital Recovery Factor (CRF) is a factor used to calculate the present value of a series of future cash flows over a specified number of years, taking into account a real interest rate. It helps determine how much a series of future payments is worth in present term and expressed by equation (7),

$$\text{Capital Recovery Factor}=I_y(1+I_y)^k/[(1+I_y)^k-1] \quad (7)$$

Cost of energy: The cost of energy (COE) is the average per-unit cost of electricity over a renewable hybrid system's entire lifespan. And it's expressed by equation (8),

$$COE=\frac{\text{Total Annualized cost of system (Can)}}{\text{Total Electricity consumption per year Et (kWh/year)}} \quad (8)$$

Where, Annualized cost (C_{an}) is the sum of capital, replacement, and annual operating costs over the system's lifetime; E_t is annual electricity consumption.

Life cycle emission: Life Cycle Emission (LCE) is the yearly equivalent of CO2 emissions (kg-eq-CO2/year) from individual components or the entire Hybrid Solar Power Generation (HSPV). The expression for n components is given by equation (9) and encompasses hazardous emissions from diverse processes.

$$LCE=\sum_{i=1}^{n} \delta iEm \quad (9)$$

Renewable Penetration: Renewable Penetration (RP) is the percentage of energy derived from sustainable sources, calculated using equation (10). It quantifies the renewable fraction in a generation system, aiding in assessing the extent of energy obtained from environmentally friendly resources and guiding evaluations of the system's sustainability and environmental impact.

$$\%RP=(1-\frac{\sum Ec}{\sum Er})*100 \quad (10)$$

OPTIMIZATION AND OUTCOMES

Simulation Report of Generic PV Plate

Generic PV Plate of 36 kW is used in HSPV model. Simulation report of Generic PV Plate 36kW is shown in **Table 3** & **Table 4**, in which the total production is 57,060 kWh/year & levelized cost is 0.119 $/kWh. **Figure 7** represents the simulation result of PV Power output.

Table 3. Simulation Report of Generic PV Plate

Quantity	Value	Units
Rated Capacity	36.0	kW
Mean Output	6.51	kW
Mean Output	156	kWh/d
Capacity Factor	18.1	%
Total Production	57,060	kWh/year

Table 4. Simulation Report of Generic PV Plate

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	35.9	kW
PV Penetration	1389	%
Hours of Operation	4,363	Hrs./year
Levelized Cost	0.119	Rupees/kWh

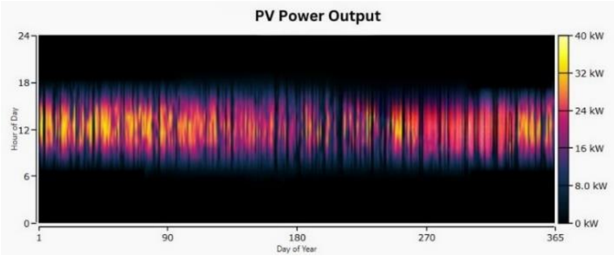


Figure 8. Simulation Result of PV Power Output

Simulation Report of Wind Turbine (90 kW)

Generic wind turbine 90 kW is selected for HSPV system. Simulation reports of Generic Wind Turbine 90 kW are shown in **Table 5 & Table 6**, in which the total production is 253,552kWh/year. **Figure 9** shows the Simulation result of Generic Wind Turbine 90 kW.

Table 5. Simulation Report of Generic Wind Turbine 90 kW

Quantity	Value	Units
Total rated Capacity	90.0	kW
Mean Output	10.9	kW
Capacity Factor	12.1	%
Total production	95,684	kWh/year

Table 6. Simulation Report of Generic Wind Turbine 90 kW

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	90.0	kW
Wind Presentation	2329	%
Hours of Operation	6,532	hrs/year
Levelized Cost	0.646	Rupees/kWh

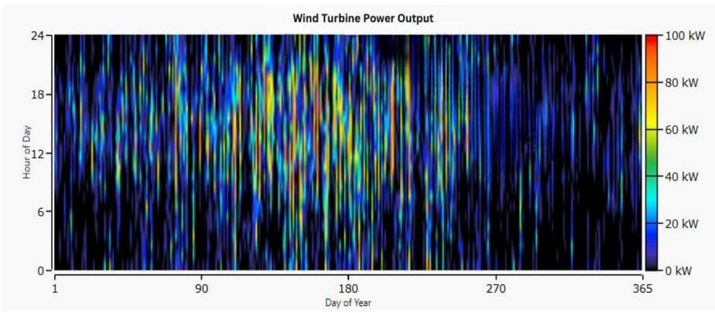


Figure 9. Simulation Result of Generic Wind Turbine (90 kW)

Simulation Report of Total Electrical Energy Production

Tables 7, 8 & 9 show the Simulation Report of Total Electrical Energy Production, in which total electrical energy production by using Generic PV Flat Plate and Generic wind turbine 90 kW is 1,53,308 kWh/year. **Figure 10** shows the Simulation Result of total electrical energy production.

Table 7. Simulation Report of Total Electrical Energy Production

Production	kWh/year	%
Generic Flat Plate PV(36 kW)	57,060	37.2
Generic Wind Turbine (90KW)	95,684	62.4
Grid Purchases	563	0.367
Total	1,53,308	100

Table 8. Simulation Report of Primary Load, Grid Sales and Total Electrical Energy Consumption

Consumption	**kWh/year**	**%**
AC Primary Load	4,109	4.16
Grid Sales	94,561	95.8
Total	98,670	100

Table 9. Simulation Report of Renewable Fraction and Max. Renewable Penetration

Quantity	**Value**	**Units**
Renewable Fraction	99.4	%
Max. Renewable Penetration	1,38,227	%

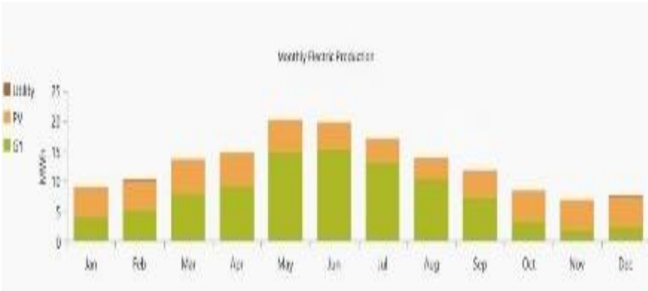


Figure 10. Simulation Result of Total Electrical Energy Production

RESULTS AND DISCUSSION

The research talks about what happened in the simulations and analyses. It looks at different ways the systems could be set up to see what's good and bad about each. This helps figure out the best way to design hybrid solar power systems in Jhansi as discussed below:

Generic Flat Plate PV vs. Integrated Generic Flat Plate PV & Wind Turbine with system converter

In the **Case-I**; Base cost system uses Generic Flat Plate PV 36.0 kW whereas lowest cost system uses Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW.

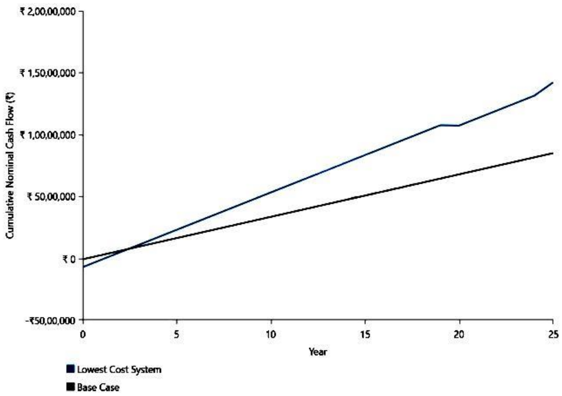


Figure 11. Comparative Cost Benefits of Generic Flat Plate PV vs. Integrated Generic Flat Plate PV &Wind Turbine with System Converter

Figure 11 shows the simulation result of Case-I, which shows that the Generic Flat PV saves Rs.3,70,892.50 per year and total saving in life time of 25 years would be Rs.92,72, 312.50 and hybrid cost system (lowest cost system) i.e., Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW, saves money Rs.6,37,694.30 per year and over the project lifetime 25 years Rs.1,59,42, 357.50. Thus, the hybrid system (Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW), is 71.9 % efficient than the base cost system.

Wind Turbine with system converter vs. Integrated Generic Flat Plate PV& Wind Turbine with system converter

In the **Case-II**; Base cost system uses Generic wind turbine 90 kW and system converter 12.0 kW whereas lowest cost system uses Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW.

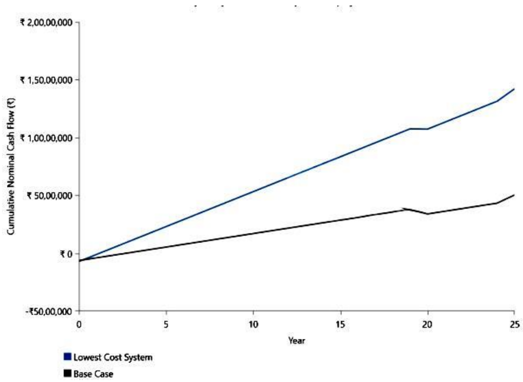
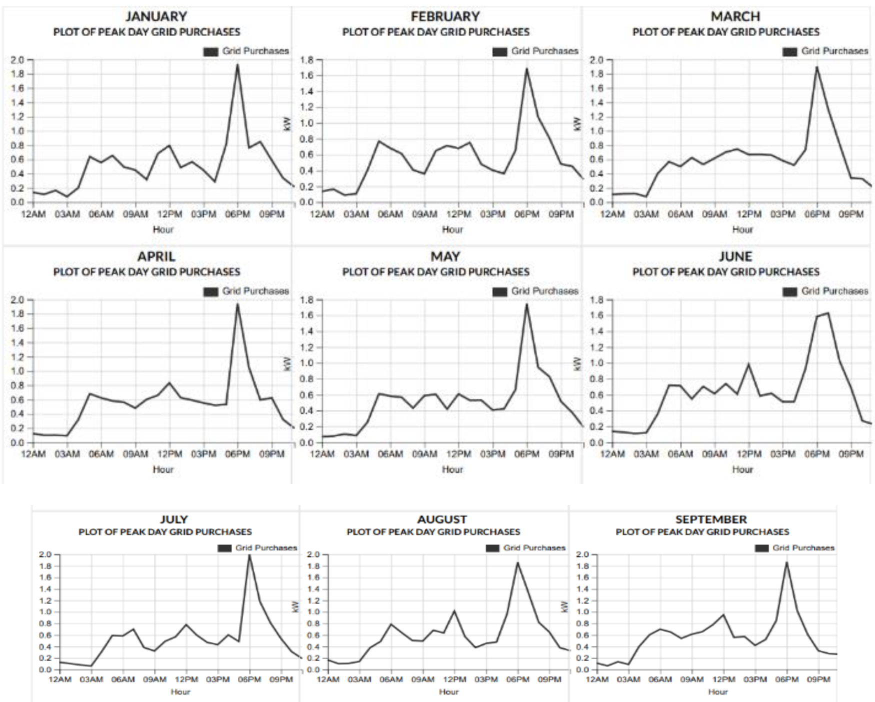


Figure 12. Comparative Cost Benefits of Wind Turbine with System Converter vs. Integrated Generic Flat Plate PV & Wind Turbine with System Converter

Figure 12 shows the simulation result of Case-II, which shows that Base cost system (uses Generic wind turbine 90 kW and system converter 12.0 kW) saves Rs.2,66,801.70 per year and total saving in life time of 25 years would be Rs. 66,70,042.50 and hybrid cost system (lowest cost system) i.e., Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW, saves money Rs.6,37,694.30 per year and over the project lifetime 25 years Rs. 1,59,42,357.50. Thus, the hybrid system (Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW), is 139.0 % efficient than the base cost system (Generic wind turbine 90 kW and system converter 12.0 kW).

Plot of Peak Day Grid Purchase

Figure 13 shows the plot of peak day grid purchase from January to December.



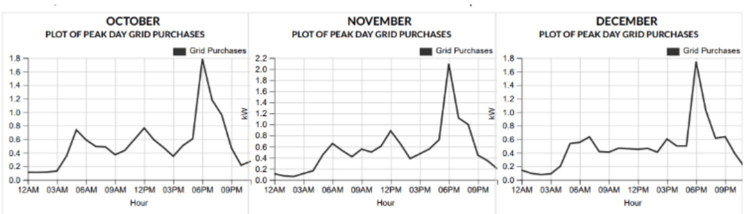
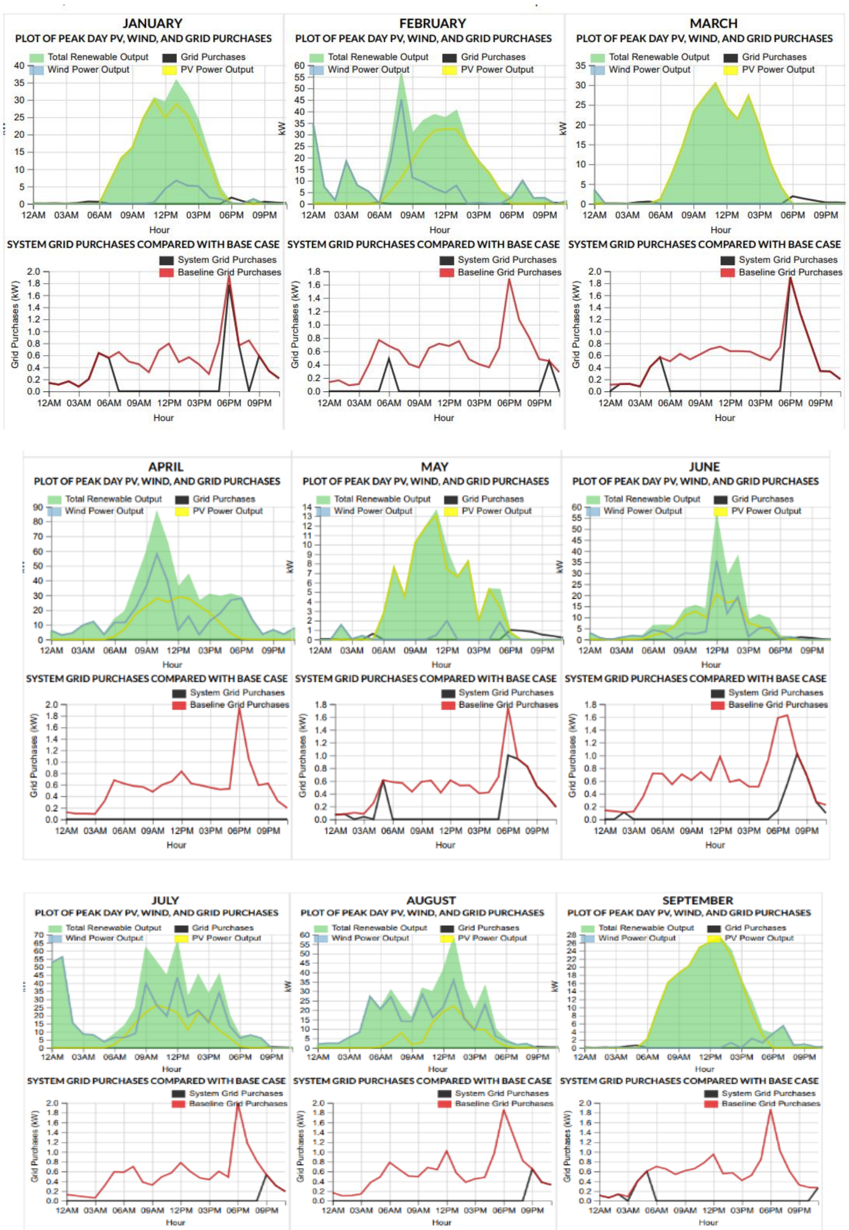


Figure 13. Plot of peak day Grid purchase from January to December

Performance Summary for Lowest Cost System

Lowest cost Hybrid Solar Power Generation is produced by Integrated Generic Flat Plate PV & Wind Turbine with system converter. Performance summary generated by HOMER SOFTWARE for lowest cost system are as follows:



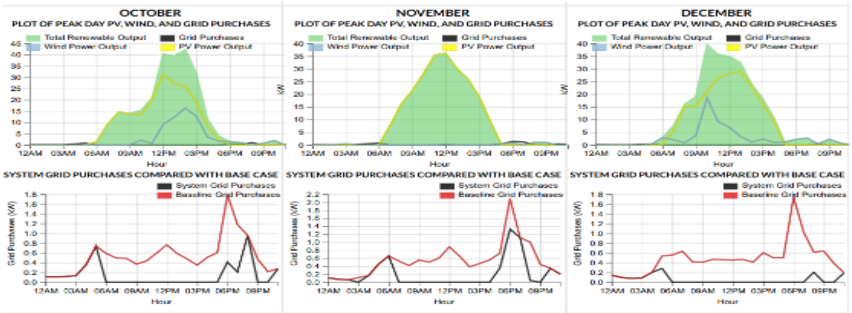


Figure 14. Performance summary for lowest cost system from January to December

The above plots give clear idea about the month wise plot of peak day PV, Wind and Grid purchases vis-a-vis System grid purchase compared with base case.

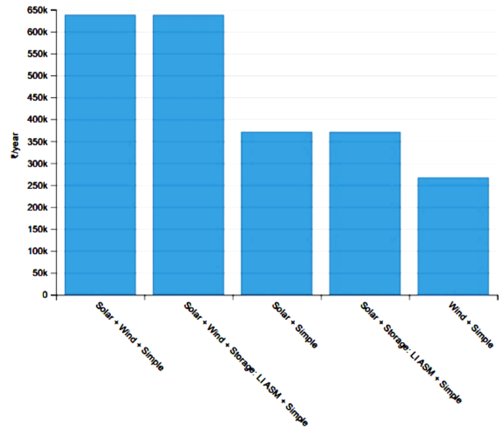


Figure 15. Project Annual Saving on Utility Bill

Figure 15 shows the project annual saving on utility bill for different combination of hybrid solar power generation system.

The results of the study indicate that the hybrid solar power generation system optimized using HOMER demonstrates significant improvements in efficiency and reliability compared to conventional standalone solar systems. From the study it is evident that both the cases have following efficiency:

- **Case-I**, which shows that the Generic Flat PV saves Rs.92,72,312.50 and hybrid cost system (lowest cost system) Rs.1,59,42, 357.50 at its life time span of 25 Years. Thus, the hybrid system (Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW), is 71.9 % efficient over the base cost system.

- **Case-II**, which shows that Base cost system (uses Generic wind turbine 90 kW and system converter 12.0 kW) saves Rs. 66,70,042.50 and hybrid cost system (lowest cost system) saves money of Rs. 1,59,42,357.50 over the project lifetime 25 years. Thus, the hybrid system (Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW), is 139.0 % efficient over the base cost system (Generic wind turbine 90 kW and system converter 12.0 kW).

Sensitivity analysis reveals the influence of various factors such as solar irradiance variability, wind velocity, and load demand on system performance. The results highlight the practical implications of the findings and identify potential challenges and limitations in implementing the proposed system in the Jhansi region.

CONCLUSION

In conclusion, the design and optimization of hybrid solar power generation systems using HOMER offer a promising approach to enhance energy efficiency and reliability in Jhansi, India. Following points are concluded:

- By leveraging available renewable resources and advanced optimization tools, it is possible to develop sustainable energy solutions tailored to the specific requirements of the region.
- The hybrid system (Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW), being 139.0 % efficient over the base cost system (Generic wind turbine 90 kW and system converter 12.0 kW), is most efficient and cost effective, can be suitable for Jhansi region.

The findings of this study contribute to the growing body of research on renewable energy systems and provide valuable insights for policymakers, energy planners, and stakeholders involved in promoting sustainable development in Jhansi and similar regions.

Nomenclature

P_S	power obtained from solar panels
In (t)	isolation at time t in kw/m^2
A_S	Single PV panel area
Eff (pv)	overall efficiency of PV panels
PR	performance ratio
H	average solar radiation on panels/year
P_W	power obtained from wind turbine
ρ	Air density
A_W	swept area
V	speed of wind
P_T	total power generated of the system
A_W	swept area
N_W	number of wind turbine
N_S	number of solar panels
t	life-time period of project
I_y	annual real interest rate
I_n	nominal interest rate
f	annual inflation rate
C_{an}	Annualized cost
E_t	annual electricity consumption

REFRENCES

[1] Jyoti Gulia, Vibhuti Garg, (2020), Institute of Energy Economics & Financial Analysis, IEEFA.org, October 2020, Wind-Solar-Hybrid-Indias-Next-Wave-of-Renewable-Growth_October-2020.pdf.

[2] Gupta, A., Kaushik, S. C., & Kaushik, S. (2019). Design and optimization of solar-wind hybrid system for rural areas using HOMER. Energy Reports, 5, 306-316.

[3] Singh, B., Sudhakar, K., & Sharma, M. P. (2020), Techno-economic analysis and optimization of a stand-alone hybrid energy system using HOMER. Sustainable Energy Technologies and Assessments, 41, 100835.

[4] Harpreet Kaur, Surbhi Gupta, Arvind Dhingra, (2022), Analysis of hybrid solar biomass power plant for generation of electric power, Volume 48, Part 5, Pages 1134-1140, https://doi.org/10.1016/j.matpr.2021.08.080,.

[5] Pranav Kadam, Rupalee Shrinivas Ambekar, (2022), Hybrid Power Generation Through Combined Solar-Wind Power System, The International journal of analytical and experimental modal analysis, August 2022, Volume XIII, Issue V, ISSN NO:0886-9367.

[6] Nishant Jha, Deepak Prashar, Mamoon Rashid, Zeba Khanam, Amandeep Nagpal, Ahmed Saeed Alghamdi, and Sultan S. Alshamrani, (2022), Energy-Efficient Hybrid Power System Model Based on Solar and Wind Energy for Integrated Grids, Volume 2022, https://doi.org/10.1155/2022/4877422.

[7] Alok Das, Hardik, K. Jani, Garlapati Nagababu, Surendra Singh Kachhwaha, (2020), A comprehensive review of wind–solar hybrid energy policies in India: Barriers and Recommendations, December 2020, Volume 35, Pages 108-121, https://doi.org/10.1016/j.ref.2020.09.004,.
[8] Faizan A.Khan , Nitai Pal , Syed. H. Saeed, (2021), Optimisation and Sizing of SPV/Wind Hybrid Renewable Energy System: A Techno-Economic and Social Perspective", May 2021, https://doi.org/10.1016/j.energy.2021.121114,.
[9] Sarang Kapoor, and Arvind Kumar Sharma, 2021, Techno-economic analysis by homer-pro approach of solar on-grid system for Fatehpur-Village, India, Journal of Phys.: Conf. Ser. 2070 012146.
[10] Vendoti Suresh, Muralidhar M. , R. Kiranmayi, (2020), Modelling and optimization of an off-grid hybrid renewable energy system for electrification in a rural areas", Energy Reports 6, 594-604, https://doi.org/10.1016/j.egyr.2020.01.013.
[11] Ashkan Toopshekan, Hossein Yousefi, Fatemeh Razi Astaraei, (2020), Technical, economic, and performance analysis of a hybrid energy system using a novel dispatch strategy", Energy 213, 118850, https://doi.org/10.1016/j.energy.2020.118850.
[12] S. Suriadi, W. I. Daru, S. R. Halid, M. Syukri and M Gapy, (2020), The optimization of hybrid power generator system (PV-Wind turbine) using Homer software, IOP Conf. Ser.: Mater. Sci. Eng. 1087 012080, 10.1088/1757-899X/1087/1/012080.
[13] Linta Khalil , Kamran Liaquat Bhatti , M. Arslan Iqbal Awan , Mughees Riaz , Kiran Khalil, Nashitah Alwaz ,(2020) "Optimization and designing of hybrid power system using HOMER pro" Journal homepage: www.elsevier.com/locate/matpr, 2 June 2020.
[14] Website of Housing: https://housing.com/news/what-is-the-1-unit-electricity-cost-in-up/
[15] Website of Smart City for Consumptions of Jhansi region https://smartcities.data.gov.in/resources/city-consumption-jhansi-2019
[16] Website of Homer Software https://www.homerenergy.com/