International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 7 (July, 2024), PP. 27-42

Designing and Optimization of Hybrid SolarPower Generation in Jhansi, India: UtilizingHOMER for Enhancing Efficiency

Garima Singh*[1]and Bharat Raj Singh[2]
*[*1]Research Scholar,*
Babu Banarasi Das Northern India Institute of Technology, Lucknow
[2]Director General (Technical), School of Management Sciences, Lucknow

Abstract
This study investigates the designing and optimizing a hybrid solar power generation system within the context of Jhansi, India, a region grappling with significant energy challenges. With the imperative of enhancing energy efficiency at the forefront, the integration of solar power with complementary renewable sources stands out as a pivotal strategy. Leveraging the advanced capabilities of HOMER software, this research embarks on a meticulous exploration of diverse system configurations to pinpoint the most efficient setup tailored specifically to the unique requirements of Jhansi.
The hybrid solar power generation, study also offers invaluable insights that resonate across diverse stakeholders, including policymakers, researchers, and industry players. In navigating the complex landscape of energy transition, these insights serve as guiding beacons, illuminating pathways towards the realization of sustainable energy solutions in India and on a global scale. As the world grapples with the imperative of transitioning towards renewable energy sources, the findings of this study serve as a testament to the transformative potential of hybrid solar power generation, underpinned by the power of advanced optimization tools like HOMER.
The results of this investigation illuminate a path towards substantial improvements in both energy generation and utilization, thereby promising noteworthy contributions to the overarching goal of sustainable development. Recognizing the multifaceted benefits of renewable energy, including its role in stabilizing energy systems, mitigating the adverse impacts of climate change, and fostering economic prosperity, the study underscores the significance of hybrid systems such as PV-Biomass and solar-wind. These integrated solutions hold promise for addressing the multifarious challenges faced by energy systemsin Jhansi and beyond. It will also demonstrate the potential for significant improvements in energy generation and utilization, contributing to sustainabledevelopment in the region.
Keywords: *Hybrid solar power generation, HOMER optimization, Renewableenergy, Sustainability, India.*

Date of Submission: 01-07-2024 Date of Acceptance: 11-07-2024

I. Introduction

The increasing demand for electricity, coupled with the urgent need for sustainable energy solutions, has ignited a surge of global interest in solar power generation systems. Particularly in regions like Jhansi, India, where energy accessibility and reliability are significant concerns, the advancement of efficient renewable energy systems holds utmost importance. Hybrid solar power generation, which blends solar energy with other renewable sources, emerges as a promising solution to address these pressing challenges.

By seamlessly integrating solar energy with other renewable sources, hybrid systems offer a comprehensive solution that not only enhances energy production but also addresses the issues of intermittency and reliability often encountered 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 windand 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 (Fig. 1).

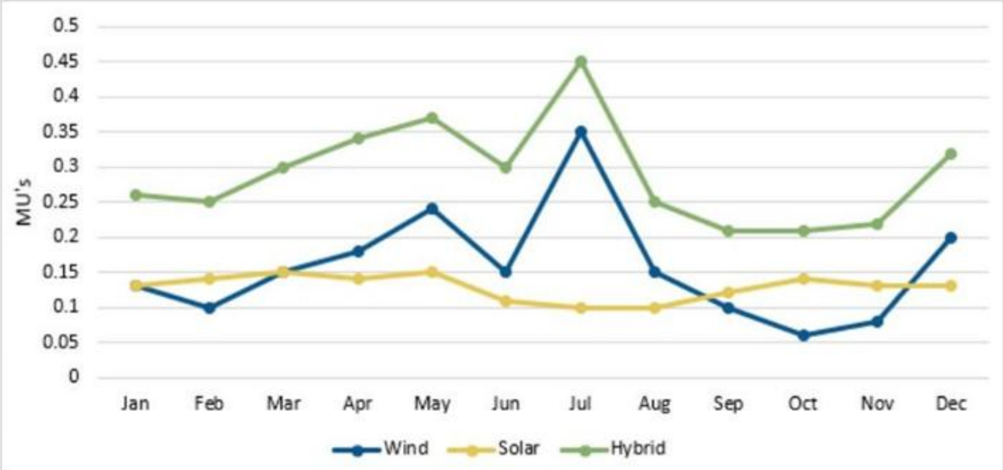


Fig. 1: India's monthly Wind, Solar and Hybrid Generation Profile

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.

In this context, the study aims to contribute to the ongoing discourse on hybrid solar power generation, focusing specifically on Jhansi's energy landscape. By leveraging advanced optimization tools such as HOMER software, the research seeks to conceptualize and fine-tune a hybrid solar power generation system customized to meet the region's distinct requirements and challenges. The goal is to lay the groundwork for a sustainable energy trajectory in Jhansi, aligning with broader national and global objectives for renewable energy integration and climate resilience.

Ultimately, the study endeavors to develop and optimize a hybrid solar power generation system in Jhansi, utilizing HOMER software to enhance both efficiency and reliability.

II. 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 hybridrenewable 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.

a. 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] explored hybrid power generation by integrating solar and wind power systems. Their project aims to establish a grid-connected hybrid power generation system that harnesses both solar and wind energy sources. The simulation and development of this system were conducted 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 areanalyzed using MATLAB.

b. Hybrid Solar Power Generation Approach

In their study, Nishant Jha et al. [6] examined an energy-efficient hybrid power system model that integrates solar and wind energy for integrated grids. The research findings indicate that incorporating hybrid PV-wind power generation units can lead to cost reductions of 10%–20% compared to current systems. This study advocates for the widespread adoption of hybrid systems in both India and globally to improve 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.

In their article titled "Wind–Solar Hybrid Energy Policies in India: Barriers and Recommendations," Alok Das et al. [7] provided a thorough review of the existing policies regarding wind–solar hybrid energy in India. The study delves into global renewable energy policies and traces the development of renewable energy policies in India from the 1990s onwards, emphasizing the initiatives undertaken to encourage renewable energy-based power generation. While onshore wind energy projects are already operational in India, offshore wind projects are still in their nascent stages and have yet to be fully explored.

Faizan A.Khan et al. [8] undertook the optimization of sizing for a SPV/Wind hybrid renewable energy system, taking into account both technological and socio-economic factors. The study scrutinized seven feasible combinations of various resources to ascertain the optimal design parameters. Employing a multi-criteria analysis, the study identified a combination of solar photovoltaic, wind, diesel generator, and battery storage as the most effective for maintaining a consistent power supply. The net present cost was calculated at $0.179, with an energy cost of $31,439. Sensitivity analysis was performed on macro- economic factors and component costs to pinpoint opportunities for enhancement. Moreover, rigorous robustness checks were carried out on the proposed system to ensure its technical and commercial viability in meeting consumer demand.

c. Role of HOMR software in Hybrid Solar Power Generation

Sarang Kapoor et al. [9] conducted a techno-economic analysis using the HOMER Pro approach to evaluate a solar on-grid system for Fatehpur-Village, India. HOMER Pro offers optimized outcomes tailored to a specific location, considering factors such as total present cost (NPC), the least cost of energy (LCOE), and operating costs. The simulation results revealed a levelized cost of energy (LCOE) of 1.77 Rs/kWh, notably lower than the grid power price of 5.6

Rs/kWh, with a total NPC of 9,291,770.00 Rs. The primary criteria utilized in this software package are NPC and LCOE to ascertain the most favorable outcomes for a given site.

Vendoti Suresh et al. [10] addressed the modeling and optimization of an off- grid hybrid renewable energy system designed for rural electrification. This project is dedicated to powering three villages within the Kollegal block of Chamarajanagar district, Karnataka State, India, utilizing an off-grid hybrid renewable energy system. The aim is to refine the system's control mechanisms, sizing specifications, and component selection to deliver a cost-effective power solution for the community. The primary objective is to minimize the Total System Net Present Cost (TNPC), Cost of Energy (COE), unmet load, and CO_2 emissions by employing Genetic Algorithm (GA) and HOMER Pro Software.

Ashkan Toopshekan et al. [11] conducted a comprehensive analysis encompassing technical, economic, and performance aspects of a hybrid energy system featuring a novel dispatch strategy. This research scrutinizes the efficacy of an on-grid photovoltaic (PV)/wind turbine (WT)/diesel/battery system tailored for a residential setting in Tehran, Iran. The system is engineered to fulfill 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] introduced the optimization of a hybrid power generator system (PV-Wind turbine) utilizing Homer software. The objective of this research was to evaluate the feasibility of a hybrid power generation system that integrates photovoltaic (PV) and wind turbine technologies, and to refine the electric energy requirements using the Hybrid Optimization Model for Electric Renewable (HOMER) software. The outcomes affirm the study's significance as a pertinent resource for governments aiming to develop power generation systems leveraging renewable energy sources.

Linta Khalil et al. [13] conducted an evaluation of a hybrid system designed for Baluchistan's Seashore, focusing on grid integration involving wind and solar installations along with converters installation to minimize grid payments. They utilized HOMER Pro software to estimate power generation, pollutant gas emissions, net present cost, and average electrical production cost. The findings demonstrate that the proposed hybrid system design emerges as the most economical option, considering operating costs, net present cost, and gas emissions.

III. Methodology

The methodology comprises several steps, commencing with the collection of data on solar irradiance patterns, energy demand, and available renewable resources within the Jhansi region [14-15]. Utilizing HOMER software [16], diverse system configurations incorporating solar panels, battery storage, and other renewable energy sources like wind power generation are modeled and simulated. The optimization process involves evaluating various parameters such as system size, component specifications, and operational strategies to enhance efficiency and minimize costs. Sensitivity analysis is conducted to gauge the impact of different factors on system performance. The most promising configurations are then identified based on predefined criteria, and their feasibility and effectiveness are thoroughly evaluated.

3.0 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.

3.1 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. The project also uses software called HOMER to analyse the city's energy usage patterns throughout the year, including daily and seasonal variations [**14-15**].
A comprehensive overview of the yearly, seasonal, and daily load profiles within the study location is offered by Fig.3, Fig.4, Fig.5, Fig. 6 and Fig.7, which were generated using HOMER SOFTWARE [**16**].

Table-1:Sector-wise Energy Consumption by Jhansi City in 2019-20 in theMonth 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

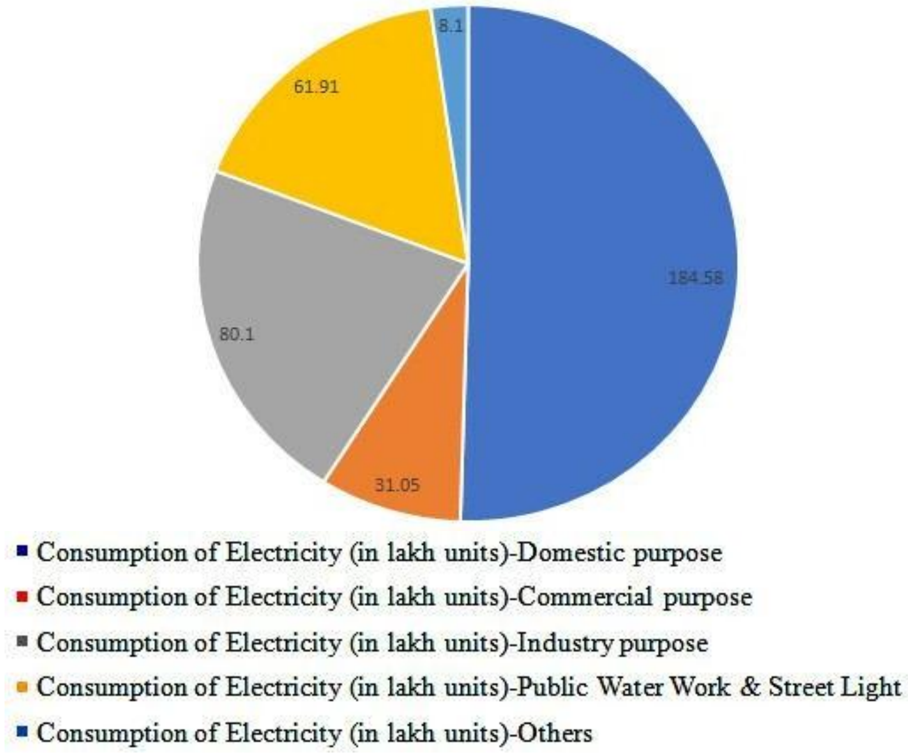


Fig.2: Sector-wise Energy Consumption by Jhansi City in 2019-20 in the Monthof January

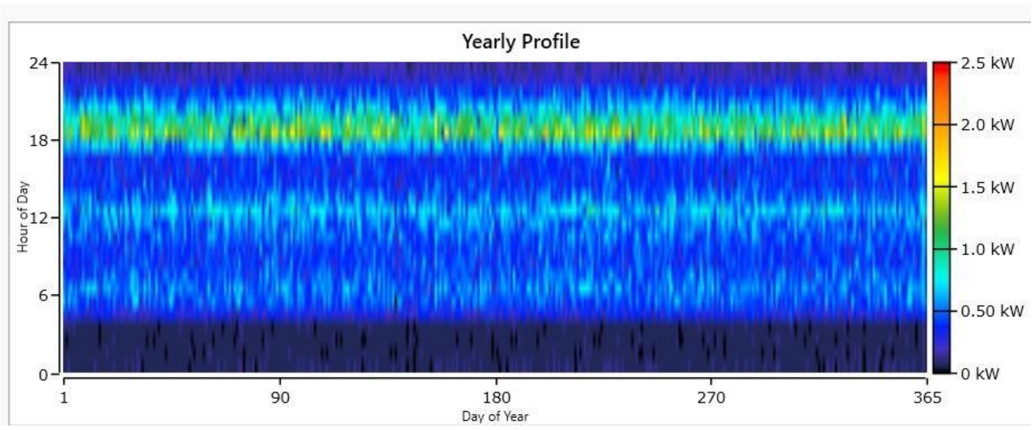


Fig.3: Yearly Load Profile within the Study of Jhansi

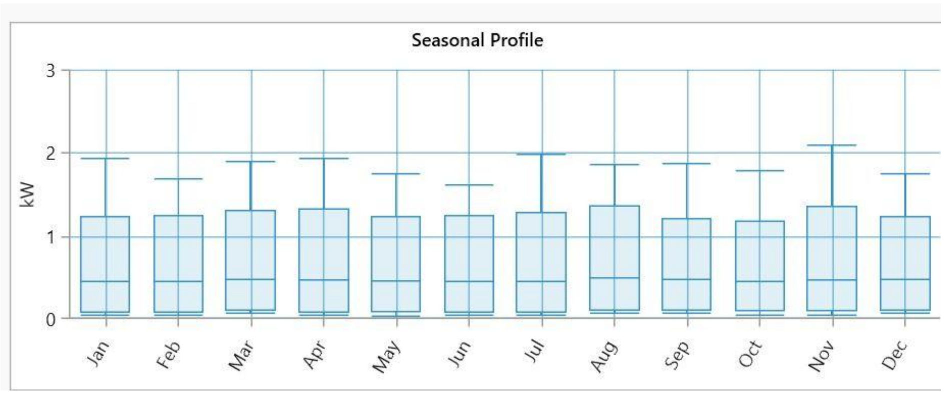


Fig.4: Seasonal Load Profile within the Study

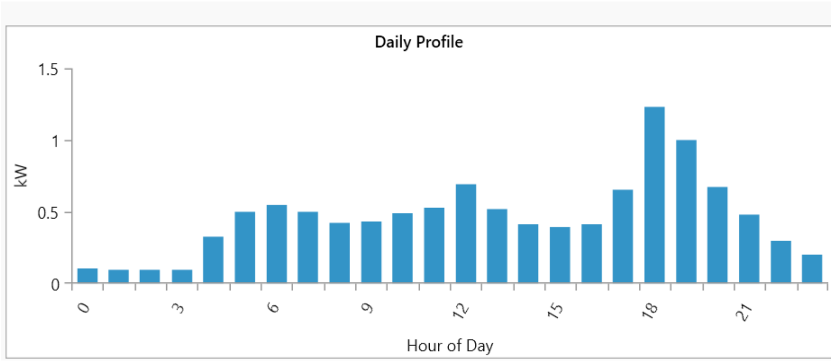


Fig.5: Daily Load Profile within the Study

3.3 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/m^2/day, was recorded in April, while the lowest, 3.840 kWh/m^2/day,was recorded in December.

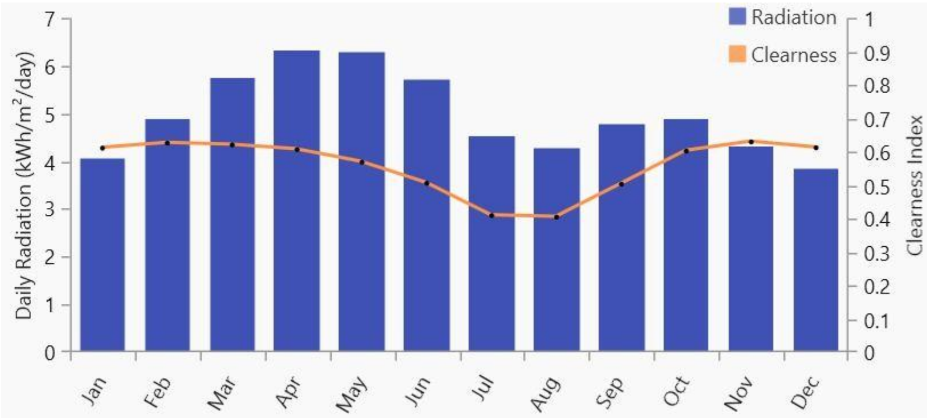


Fig. 6: Annual Solar Radiation within the Study

3.4 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.

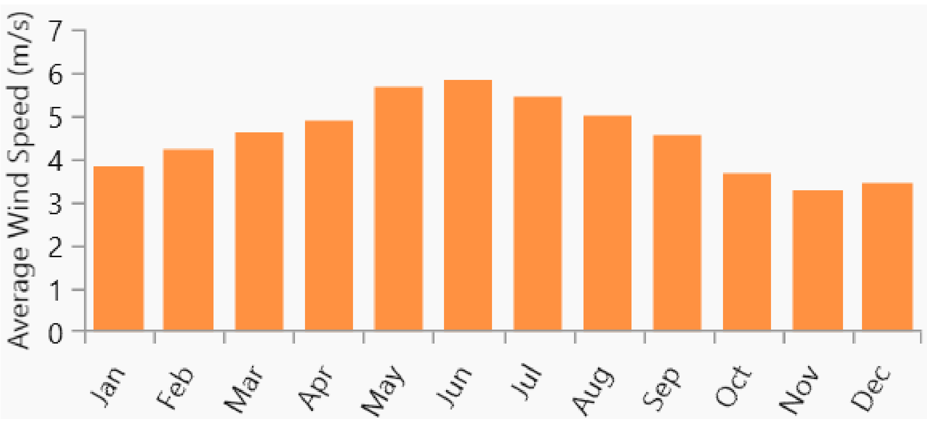


Fig. 7: Annual Monthly Wind Speed within the Study

IV. Statistical Analysis

4.1 Mathematical Modelling of solar and Wind Panel

i. **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).

$P_S = In(t) * A_S * Eff(pv)$ (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 ofPV panels

For representation of overall efficiency,

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

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

ii. **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

iii. **Systemconverter:** 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.

iv. **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].

$P_W = ½□A_W V^3$ (3)

As, P_W indicates power obtained from wind turbine, □ is air density, A_W isswept 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.

$P_T = N_W*P_W + N_S*P_S$ (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].

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

b. Criteria of Evaluation

i. **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 equation (5),

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

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

ii. **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 expressedby equation (8),

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

iii. **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.

δiEm LCE=$\sum_{i=1}^{n}$ (9)

iv. **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=)*100 (10) $(1 - \frac{\sum Ec}{\sum Er}$

V. Optimization and Outcomes

5.1Simulation 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 & 4, in which the total production is 57,060 kWh/year & levelized cost is 0.119 $/kWh. **Fig. 7** represents the simulation result of PV Power output.

Table3: SimulationReportofGenericPVPlate

Quantity	**Value**	**Units**
Rated Capacity	36.0	kW
MeanOutput	6.51	kW
MeanOutput	156	kWh/d
CapacityFactor	18.1	%
TotalProduction	57,060	kWh/year

Table4: Simulation Report of Generic PV Plate

Quantity	Value	Units
MinimumOutput	0	kW
MaximumOutput	35.9	kW
PVPenetration	1389	%
HoursofOperation	4,363	Hrs./year
LevelizedCost	0.119	Rupees/kWh

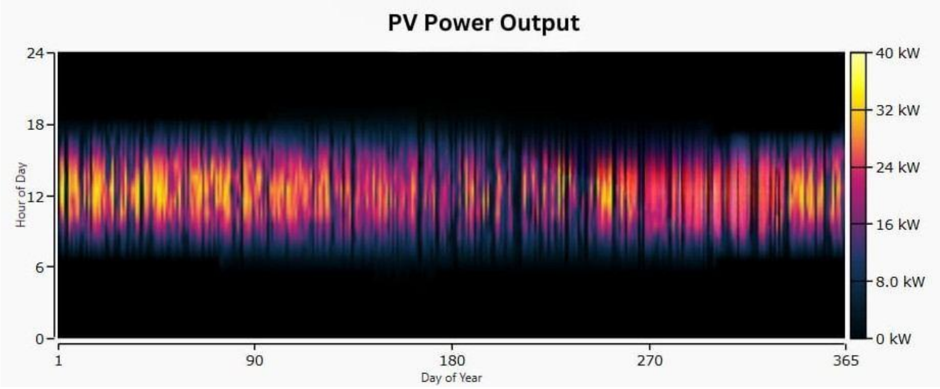


Fig.8: Simulation Result of PV Power Output

5.2Simulation 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 & 6, in which the total production is 253,552kWh/year. **Fig. 9** shows the Simulation result of Generic Wind Turbine 90 kW.

Table-5: Simulation Report of Generic Wind Turbine 90 kW

Quantity	Value	Units
TotalratedCapacity	90.0	kW
MeanOutput	10.9	kW
CapacityFactor	12.1	%
Totalproduction	95,684	kWh/year

Table-6: SimulationReportofGeneric Wind Turbine 90 kW

Quantity	Value	Units
MinimumOutput	0	kW
MaximumOutput	90.0	kW
WindPresentation	2329	%
HoursofOperation	6,532	hrs/year
Levelized Cost	0.646	Rupees/kWh

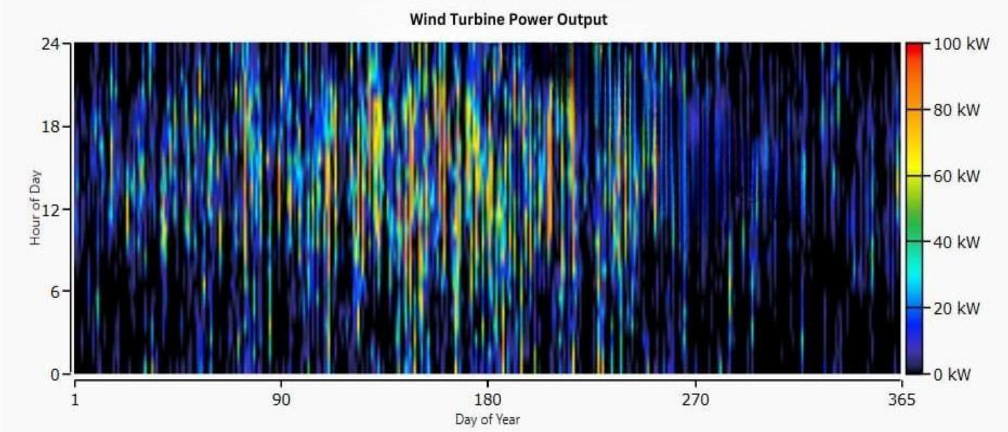


Fig.9: Simulation Result of Generic Wind Turbine (90 kW)

3Simulation 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. **Fig. 10**shows the Simulation Result of total electrical energy production.

Table-7: SimulationReportofTotalElectricalEnergyProduction

Production	**kWh/year**	**%**
GenericFlatPlatePV(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: SimulationReportofPrimaryLoad,GridSalesandTotalElectricalEnergyConsump tion

Consumption	**kWh/year**	**%**
ACPrimaryLoad	4,109	4.16
GridSales	94,561	95.8
Total	98,670	100

Table-9: SimulationReportofRenewableFractionandMax.RenewablePenetration

Quantity	**Value**	**Units**
RenewableFraction	99.4	%
Max.RenewablePenetration	1,38,227	%

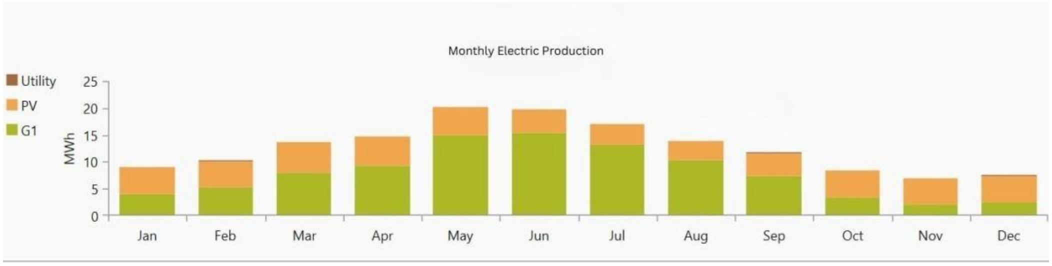


Fig.10: SimulationResultofTotalElectricalEnergyProduction

VI. 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:

6.1 Generic Flat Plate PV vs. Integrated Generic FlatPlatePV&WindTurbine 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 kWand system converter 12.0 kW.

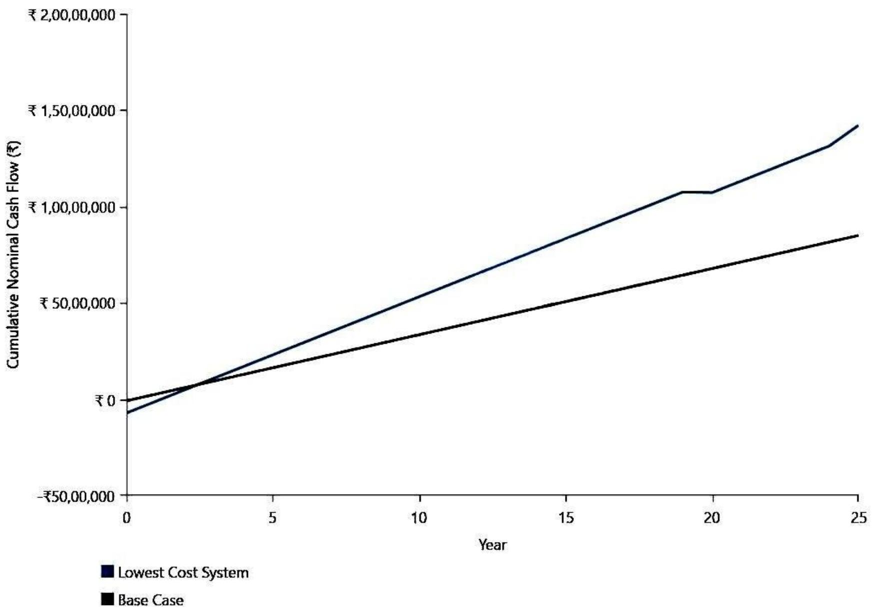


Fig.11: Comparative Cost Benefits of Generic Flat Plate PV vs. IntegratedGeneric Flat Plate PV &Wind Turbine with System Converter

Fig. 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 wouldbe 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 thehybrid 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.*

a. WindTurbine with system convertervs. Integrated Generic FlatPlatePV&WindTurbine 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.

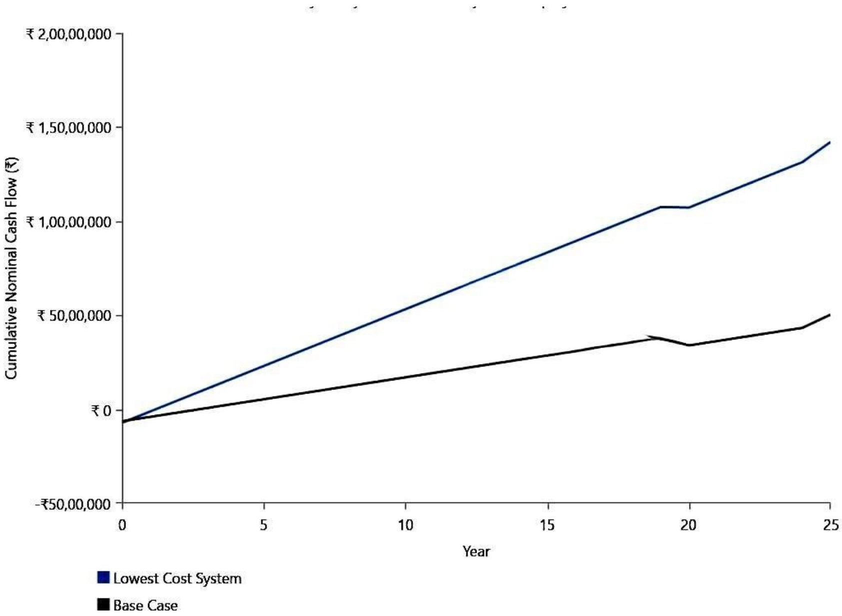


Fig.12: Comparative Cost Benefits of Wind Turbine with System Converter vs. Integrated Generic Flat Plate PV &Wind Turbine with System Converter

Fig. 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 thehybrid system (*Generic Flat Plate PV 36.0 kW, Generic wind turbine 90 kW and system converter 12.0 kW), is 139.0 % efficientthan the base cost system (*Generic wind turbine 90 kW and system converter 12.0 kW).

6.3 Plot of Peak Day Grid Purchase

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

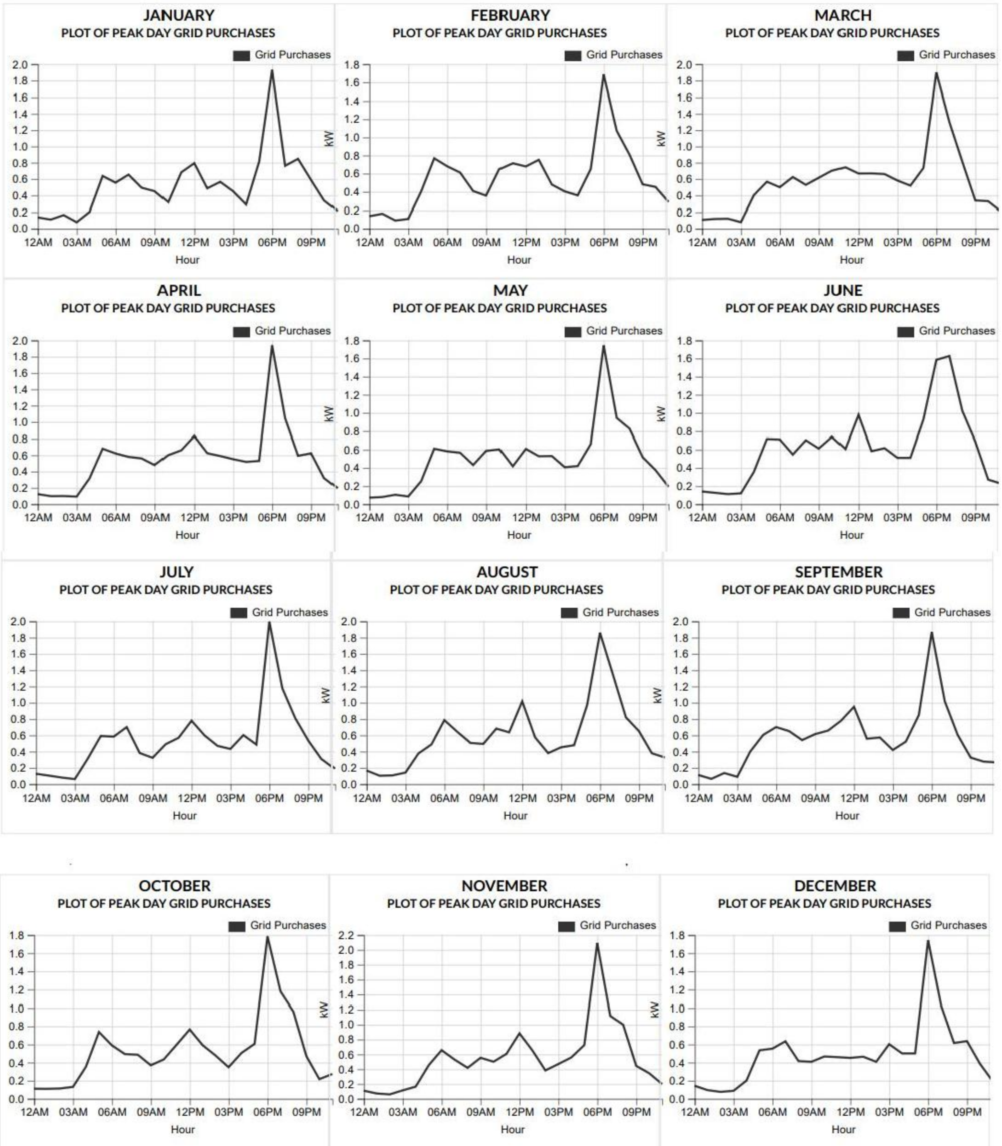
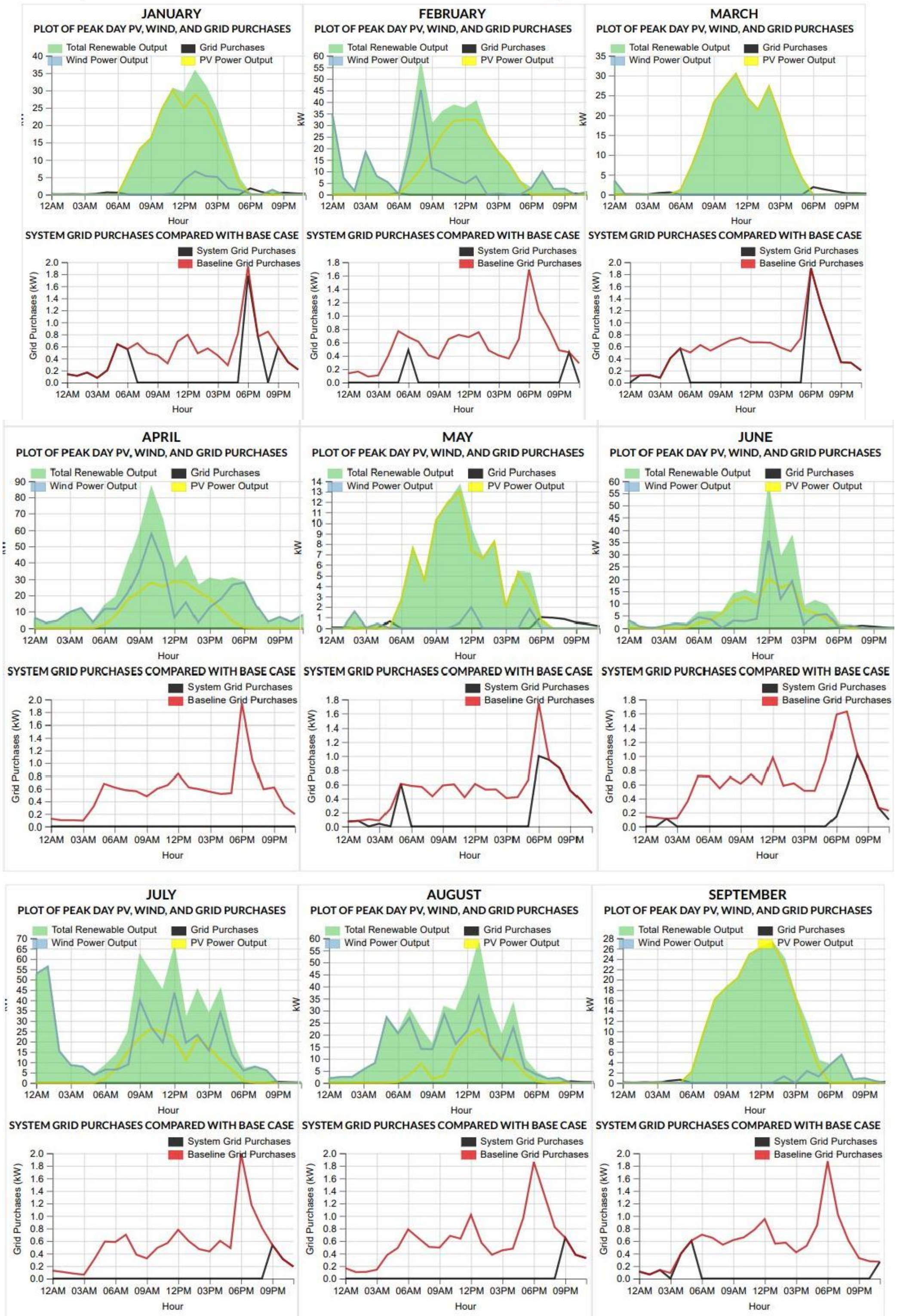


Fig. 13: Plot of peak day Grid purchase from January to December

6.4 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 generatedby HOMER SOFTWARE for lowest cost system are as follows:


JANUARY
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
Total Renewable Output
Grid Purchases
Wind Power Output
PV Power Output
Hour
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
System Grid Purchases
Baseline Grid Purchases
Grid Purchases (kW)
Hour
FEBRUARY
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
kW
Hour
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
MARCH
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
APRIL
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
MAY
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
JUNE
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
JULY
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
AUGUST
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
SEPTEMBER
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE

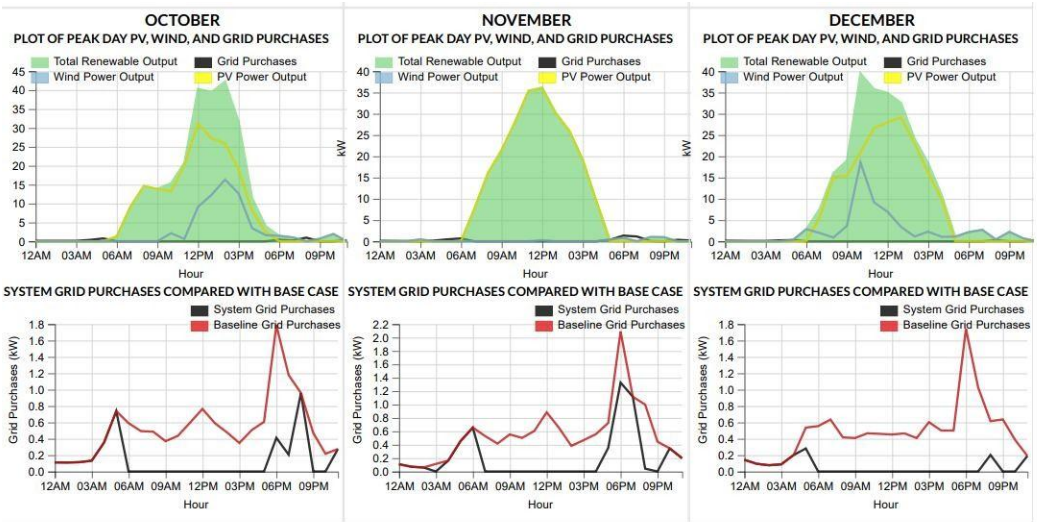


Fig. 14: Performance summary for lowest cost system from January to December

The above plots gives 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.

suitable and

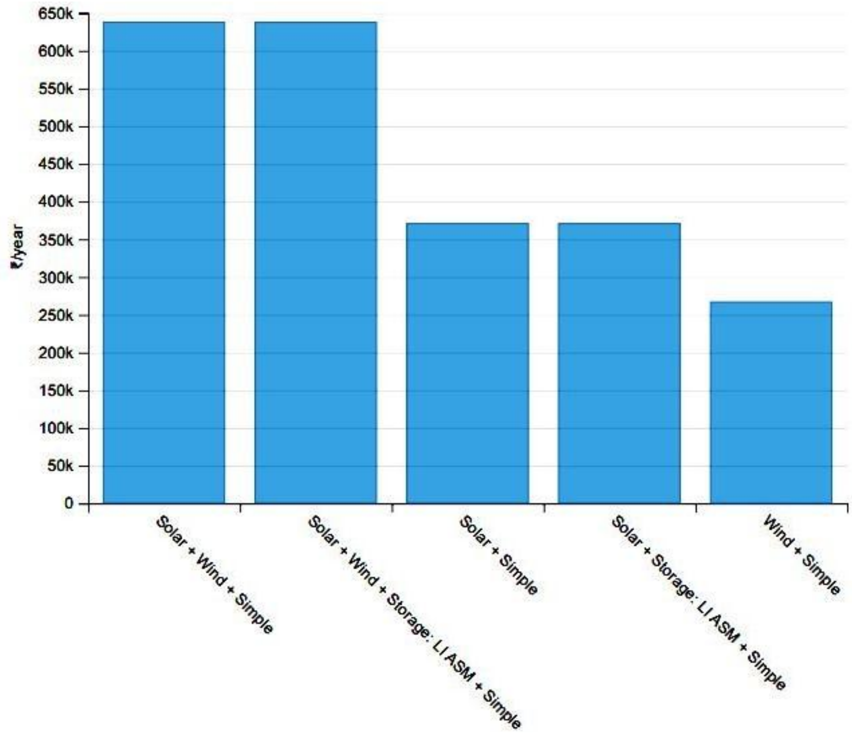


Fig.15: Project Annual Saving on Utility Bill

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 thehybrid 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. 1,59,42,357.50over the project lifetime 25 years. Thus thehybrid 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.

VII. 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:

i. By leveraging available renewable resources and advanced optimization tools, it is possible to develop sustainable energy solutions tailored to thespecific requirements of the region.

ii. Thehybrid system (*Generic Flat Plate PV 36.0 kW, Generic wind turbine90 kW and system converter 12.0 kW), being 139.0 % efficient over the base cost system (*Generic wind turbine 90 kW and system converter 12.0kW), is most efficient and cost effective, can besuitable 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.

References

[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/