ISSN: 2633-4828 Vol. 6 No.1, January, 2024

International Journal of Applied Engineering & Technology

TECHNO-ECONOMIC ANALYSIS AND DESIGN OF HYBRID SOLAR POWER GENERATION OPTIMIZATIONIN UDAIPUR, INDIA

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ABSTRACT

This research paper presents a comprehensive investigation into the techno-economic aspects and design optimization of hybrid solar power generation in Udaipur, India, utilizing the advanced features of the HOMER software. Integration of solar energy with other power sources is pivotal for improving reliability, efficiency, and economic feasibility. Through extensive simulations and analyses, the study aims to offer valuable insights into the optimal configuration of a hybrid solar power system tailored to the unique characteristics of the Udaipur region.

The paper concludes by summarizing key findings, discussing implications for the deployment of hybrid solar power systems in Udaipur, and providing recommendations for future research. The techno-economic analysis and design optimization presented herein provide valuable guidance for policymakers, energy planners, and researchers striving for sustainable energy solutions in similar regions.

The analysis from 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 and XANT M-21(100kW) wind turbine), Case-II (Base cost system uses XANT M-21 (100kW) wind turbine, converter 0.33kW and battery storage LI ASM 3.00 whereas lowest cost system uses Generic Flat Plate PV 36.0 kW and XANT M-21(100kW) wind turbine), and Case-III (Base cost system uses XANT M-21 (100kW) wind turbine whereas lowest cost system uses Generic Flat Plate PV

36.0 kW and XANT M-21(100kW) wind turbine) sheds light on the cost-effectiveness and performance of various hybrid solar power system setups. Results indicate that integrating wind energy alongside solar power leads to economic advantages over the project's lifetime. Specifically, the integration of wind energy in hybrid systems demonstrates potential savings and enhanced cost-effectiveness.

Thus, the research underscores the economic viability and cost-saving potential of hybrid solar power systems incorporating wind energy. These findings emphasize the importance of considering hybrid configurations for sustainable and economically beneficial renewableenergy solutions, particularly in regions like Udaipur.

Keywords: Solar power, Wind energy, Hybrid solar power, Techno-economic, Analysis and design, HOMER software

1.0 INTRODUCTION

The escalating global demand for sustainable energy solutions has propelled a profound shift towards renewable sources, among which solar power stands out prominently. Udaipur, nestled in a region abundant with sunlight, epitomizes an ideal locale for the harnessing of solar energy. This paper embarks on an exploration of integrating solar power with other energy sources using the HOMER software, renowned for its adeptness in optimizing hybrid power systems.

Our research endeavors to undertake a comprehensive investigation into the techno-economic facets and design optimization of hybrid solar power generation in Udaipur, India, leveraging the sophisticated capabilities of the HOMER software. The integration of solar energy with alternate power sources assumes paramount significance in enhancing reliability, efficiency, and economic viability. Through an exhaustive array of simulations and analyses, our study aspires to furnish valuable insights into configuring an optimal hybrid solar power system finely attuned to the distinctive attributes of the Udaipur region.

Moreover, this paper concludes by summarizing the essence of our discoveries, exploring their implications for implementing hybrid solar power systems in Udaipur, and providing suggestions for future research pursuits. The techno-economic analysis and design optimization presented here offer invaluable guidance for policymakers, energy planners, andresearchers striving to develop sustainable energy solutions in similar regions.

The classification into Case-I, Case-II, and Case-III throws light on the cost-effectiveness and performance measures of various hybrid solar power system setups. These results emphasize the economic advantages achievable throughout the project's duration by combining wind energy with solar power. Particular significance are the clear cost reductions and increased cost-effectiveness resulting from integrating wind energy into hybrid systems.

Hence, our research underscores the economic viability and potential cost-saving dividends associated with hybrid solar power systems amalgamating wind energy. These findings highlight the importance of considering hybrid configurations as crucial components for sustainable and economically beneficial renewable energy solutions, especially in regions similar to Udaipur.

2.0 LITERATURE REVIEW

The global pursuit of sustainable energy solutions has intensified in recent years, driven by concerns over climate change and the depletion of finite energy resources. Renewable energy sources, particularly solar power, have emerged as pivotal components of this transition towards sustainability. As the demand for clean energy continues to rise, researchers and policymakers are increasingly exploring innovative approaches to maximize the efficiency and effectiveness of renewable energy systems. This section provides a comprehensive review of the existing literature on hybrid solar power systems, with a focus on their applications and the role of techno-economic analysis in ensuring their feasibility and economic viability.

A review of existing literature outlines the current state of hybrid solar power systems and their applications. Previous studies have emphasized the importance of techno-economic analysis in ensuring the feasibility and economic viability of such systems. The HOMER software has been acknowledged as a valuable tool for optimizing the design and operation ofhybrid power systems.

2.1 CURRENT STATE OF HYBRID SOLAR POWER SYSTEMS

Hybrid solar power systems, which integrate solar energy with other renewable energy sources such as wind, biomass, or hydroelectric power, have garnered significant attention in the renewable energy sector. These systems offer several advantages over standalone solar or conventional power generation methods, including enhanced reliability, increased energy output, and improved cost-effectiveness. By harnessing multiple energy sources, hybrid systems can mitigate the intermittency and variability inherent in solar and wind energy generation, thereby providing a more stable and consistent power supply.

Numerous studies have explored the design, optimization, and performance evaluation of hybrid solar power systems in various geographical locations and applications. For instance, research by **Juan Carlos León Gómez et. al [1]** focused on the hybrid renewable energy systems: architectures, battery systems, and optimization techniques. Hybrid renewable energy systems (HRESs) are increasingly popular for grids, requiring designers to balance cost and efficiency. Battery energy storage systems (BESS) are crucial, especially in microgrids, for managing energy balance. Optimizing HRESs involves classical, artificial, and hybrid methods, with a focus on techno-economic aspects and software like HOMER. Similarly, studies by **Qusay Hassan et. al [2]**discussed hybrid renewable energy systems: solar and wind-powered solutions: challenges, opportunities, and policy implications. This paper concluded that energy storage technologies, especially batteries, play a crucial role in enhancing the performance of hybrid renewable energy systems (HRES) by addressing the intermittent nature of renewable sources. Optimizing energy storage involves strategies considering cost, degradation, and emerging technologies like ultra-capacitors. HRES configurations and control strategies are versatile, offering sustainable energy solutions.**Dario Cyril Muller et. al [3]** focused on simulation of hybrid solar, wind, and energy storage system for a sustainable campus. The analysis of wind and solar energy configurations in Manipal, India reveals that a combination of solar PV, wind generation, and battery storage is optimal. The daylight-congruent load curve, peaking from noon to late afternoon, reduces the need for storage. Wind energy maximization further supports this optimal configuration. **Pranoy Roy et. al [4]** focused on recent advances of wind-solar hybrid renewable energy systems for power generation. This paper provides a detailed review of wind-solar hybrid renewable energy systems (HRES), covering system modelling, power converter configurations, optimal design algorithms, and degradation models for batteries and supercapacitors. It includes a critical review of HESS topologies, a comparative study of power converter configurations, and an analysis of commonly used optimization algorithms. The review aims to identify and address technical gaps to improve future HRES development.

2.2 IMPORTANCE OF TECHNO-ECONOMIC ANALYSIS

Techno-economic analysis plays a crucial role in the development and implementation of hybrid solar power systems by providing valuable insights into their technical feasibility, economic viability, and environmental impact. This multidisciplinary approach involves assessing various factors such as capital costs, operating expenses, energy output, and environmental benefits to determine the overall cost-effectiveness and sustainability of hybridsystems.

Previous studies have underscored the significance of techno-economic analysis in guiding decision-making processes related to renewable energy investments and policy formulation. For instance, research by **Iman Rahimi et. al [5]** conducted a techno-economic analysis for using hybrid wind and solar energies in Australia. This paper presented a feasibility study on using a hybrid of wind and solar energies in five Australian cities: Sydney, Brisbane, Perth,

Melbourne, and Adelaide. It analyzed ten building types and proposed optimal energy configurations based on load profiles and cost analysis, including NPC and operating costs. The study aimed to promote the use of hybrid renewable energy sources to replace all electricity provided to these locations, thereby reducing Australia's impact on climate change and greenhouse gas emissions. The results provide practical scenarios and optimal configurations that can serve as guidelines for designing power systems. Similarly, studies by**Munish Manas et. al [6]** presented a review on techno-economic analysis of hybrid renewable energy resources-based microgrids. Integration of flow power systems is crucial for sustainable energy supply, with research advancing in understanding sources, comparing storage, sizing systems, and designing power control. Extending storage lifespan, especially batteries, is key, requiring tech and management advancements. Forecasting resource improvements use meteorological and AI methods. Lowering component costs like; PV panels, boosts system viability. Ensuring stability with renewable needs better control and grid tech. Hybrid systems combining renewable and storage enhance reliability. Efficient energy management and grid integration are complex but vital. Environmental impact assessments are essential for long-term sustainability, focusing on reducing ecological footprints. **Mustafa M.A. Seedahmed et. al [7]** utilized a techno-economic analysis of a hybrid energy system for the electrification of a remote cluster in western Saudi Arabia. This paper concluded that the feasibility study used HOMER to analyze financial parameters and conducted sensitivity investigations. The wind/DG/FC/battery hybrid off-grid system was found to be the most economic and eco-friendly solution.

2.3 ROLE OF HOMER SOFTWARE

The HOMER software platform has emerged as a valuable tool for optimizing the design and operation of hybrid power systems, including hybrid solar configurations. Developed by the National Renewable Energy Laboratory (NREL), HOMER enables users to model, simulate, and analyze various renewable energy technologies and system configurations to identify the most cost-effective and efficient solutions for specific applications.

Several studies have utilized HOMER software to conduct techno-economic analysis and design optimization of hybrid solar power systems in diverse geographical locations. For example, research by **Sylvester William Chisale et. al [8]** conducted optimization and designof hybrid power system using HOMER pro and integrated

CRITIC-PROMETHEE II approaches. This paper concluded a persistent power supply issues in Malawi necessitate resource diversification. This study analyses a hybrid system for a school, aiming for reliability, cost reduction, and decreased grid dependency. Six scenarios combining grid, diesel, solar PV, wind, biogas, and battery were evaluated using HOMER Pro and CRITIC- PROMETHEE II. The optimal configuration includes grid, solar PV, and biogas from human waste. Despite inflation's impact, the system's levelized cost of electricity (0.095 $/kWh) is lower than the grid's (0.11 $/kWh). This approach could reduce greenhouse emissions and improve energy access, suggesting investment in alternative energy for schools and governments. Similarly, studies by **Ashkan Toopshekan et. al [9]** performed a technical, economic, and performance analysis of a hybrid energy system using a novel dispatch strategy. This study in Tehran, Iran, evaluates an on-grid PV/WT/Diesel/Battery system for residential use. A new dispatch strategy using MATLAB Link in HOMER software improvesenergy cost by over 9% compared to standard strategies. The renewable fraction is also higher. Sensitivity analysis explores various loads, grid prices, and equipment costs to determine system optimality boundaries. **Ali Saleh Aziz et. al [10]** conducted a case study on optimization and sensitivity analysis of standalone hybrid energy systems for rural electrification in Iraq. This paper concluded that off-grid hybrid energy systems (HESs) are more cost-effective and reliable than single-source systems for rural electrification. A study in Iraq analyzes various HES configurations using HOMER software, including a PV/hydro/diesel/battery system. The most economical option has a net present cost (NPC) of $113201, with acceptable technical and environmental performance. Over 20 years, PV production decreases by 9.1%, while diesel production, CO2 emissions, and served load increase significantly. Sensitivity analysis of parameters like water pipe losses and battery efficiency shows their significant impact on system performance and economics, highlighting the importance of accurate modelling for off-grid HES design.

Thus, the literature review highlights the increasing significance of hybrid solar power systems as a key component of sustainable energy solutions worldwide. These systems offer numerous advantages, including enhanced reliability, increased energy output, and improved cost-effectiveness, making them well-suited for diverse applications ranging from rural electrification to grid integration. Moreover, techno-economic analysis, facilitated by tools like HOMER software, plays a crucial role in guiding the design, optimization, and implementation of hybrid systems by providing valuable insights into their feasibility and economic viability. Moving forward, further research and development efforts are needed to advance the state-of-the-art in hybrid solar power systems and accelerate their widespread adoption in the transition towards a sustainable energy future.

3.0 METHODOLOGY

The methodology involves the collection of relevant data on solar irradiance, load demand, and other pertinent parameters specific to the Udaipur region. The HOMER software is then employed to model and simulate various hybrid power system configurations. The objective is to identify the optimal combination of solar and other power sources to meet the energy demand efficiently and economically.

3.1 EVALUATION CRITERIA

Choosing the right evaluation criteria is crucial when examining the operational dynamics of different scenarios in Renewable Energy projects. This study employs a specific methodology to ensure a comprehensive analysis. The process involves careful consideration and selection of criteria that align with the unique characteristics and goals of Renewable Energy projects. By employing a systematic approach, the study aims to provide a thorough understanding of the operational behaviour of these projects under various scenarios.

3.1.1 Specification of the Selected Site: Udaipur city, situated in the southernmost part of Rajasthan near the Gujarat border, is encompassed by the majestic Aravali Range, acting as a natural barrier against the Thar Desert. The geographical coordinates of Udaipur are approximately 24.525049°N latitude and 73.677116°E longitude. Spanning an area of 64 km²(25 sq. mi), the city graces an elevation of 598.00 m (1,962 ft) above sea level. Its climate is characterized by a hot semi-arid pattern, with the summer season extending from mid-March to June. During this period, temperatures fluctuate between 23 °C (73 °F) and 44 °C (111 °F). Notably, even in January, the coldest month, Udaipur experiences bright, sunny days with a maximum temperature reaching around 28.3 °C (82.9 °F) **[11, 12, 13]**.

3.1.2 Energy Demand Estimation: The research project envisions an escalating energy demand trend, with a specific focus on local requirements encompassing domestic, agricultural, community, and commercial loads. Survey data has been meticulously gathered to outline energy consumption patterns across various sectors such as health centers, schools, shops, street lighting, water pumping, and small industries. In the fiscal year 2019-2020, the total energy demand for Udaipur city was recorded at 1,00,94,646 GJ **[14]**. Fig.1 and Table- 1 provide an insightful breakdown of sector-wise energy consumption in the city during that period. Additionally, Fig.2, Fig.3, Fig.4 and Fig.5, generated using HOMER SOFTWARE, offer a comprehensive overview of the yearly, seasonal, and daily load profiles within the study location **[15].**

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

Sector	Energy Use (GJ)
Stationary Units	**69,13,259**
Residential Buildings	33,22,213
Commercial and Institutional Buildings/ Facilities	10,54,457
Manufacturing Industry and Construction(i.e., Industrialsector)	25,06,890
Agriculture, forestry and fishing activities (i.e., mainly agriculture)	29,700
Mobile Units	31,81,387
On-Road Transportation	31,81,387
Total	**1,00,94,646**

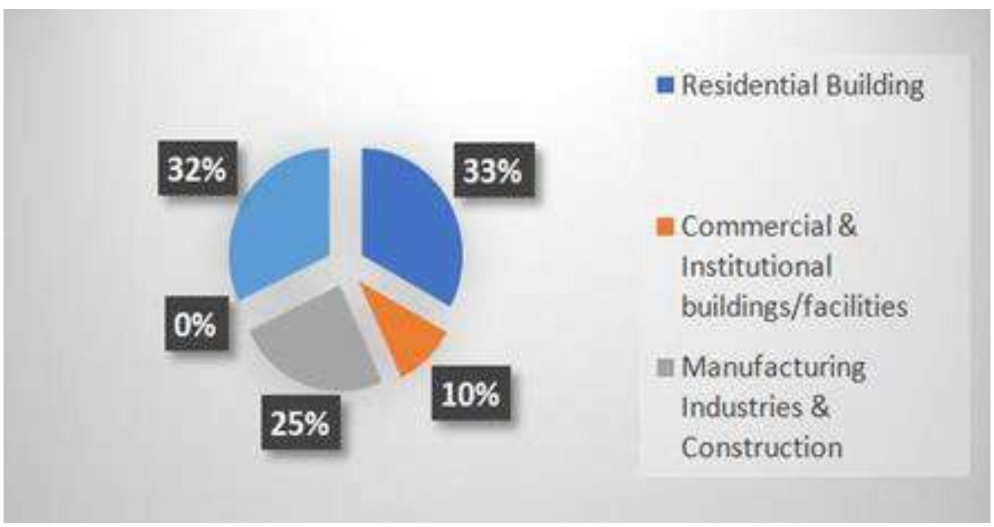

Fig. 1: Sector-wise Energy consumption in Udaipur, (2019-20)

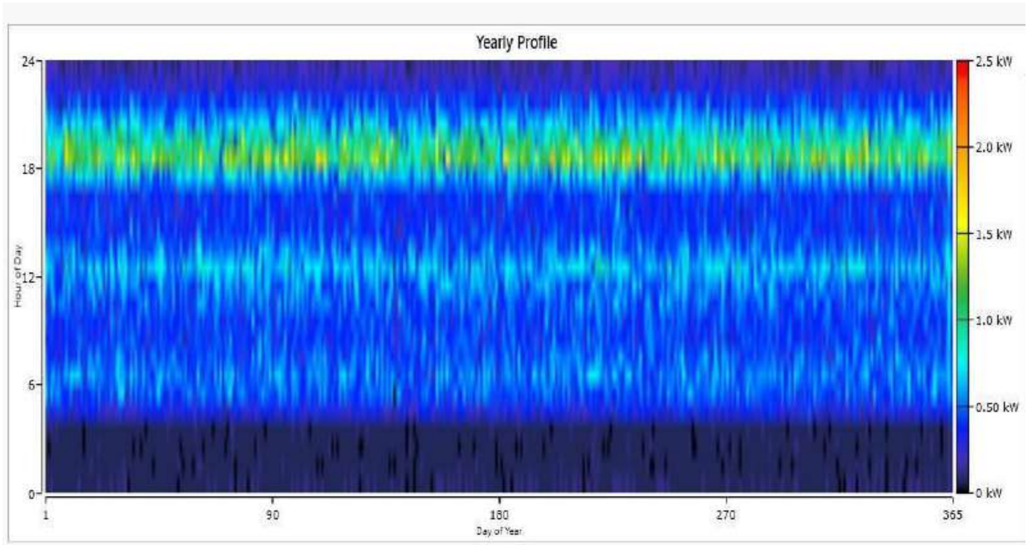

Fig. 2 Yearly load profile within the study

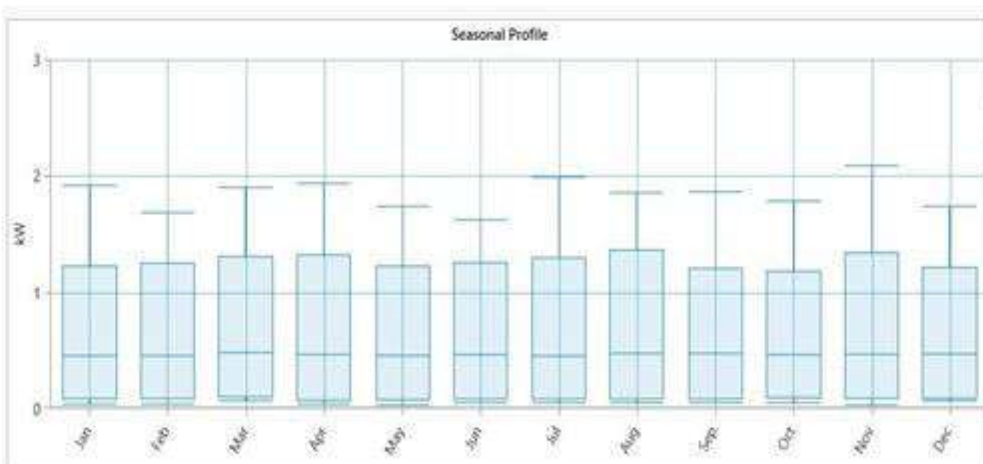

Fig.3 Seasonal load profile within the study

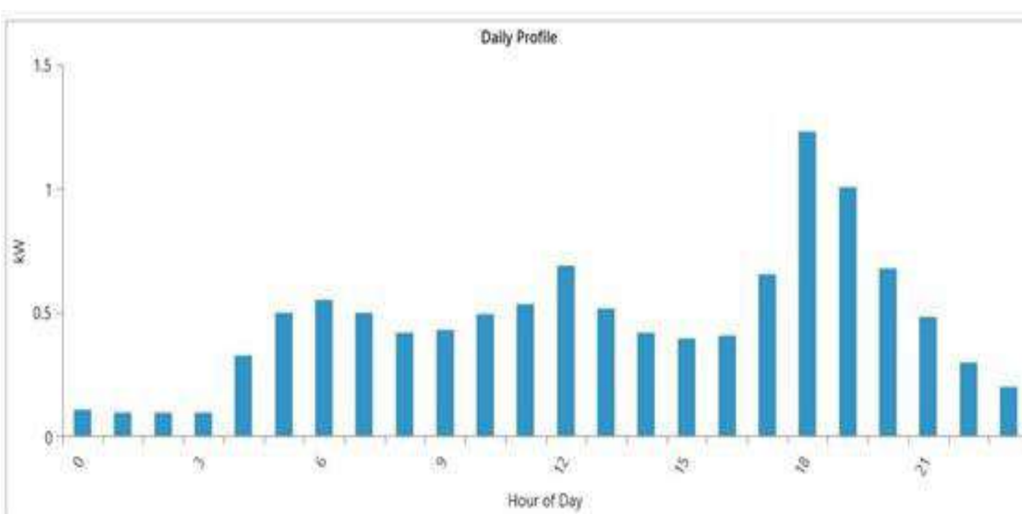

Fig.4 Daily load profile within the study

3.1.3 Annual solar Radiation: Annual daily solar irradiation available within the study location is shown in **Fig.5** as per HOMER SOFTWARE. Highest solar irradiation found as:

7.011 kWh/m^2/day in the month of May, whereas lowest as: 4.922 kWh/m^2/day was found inDecember month.

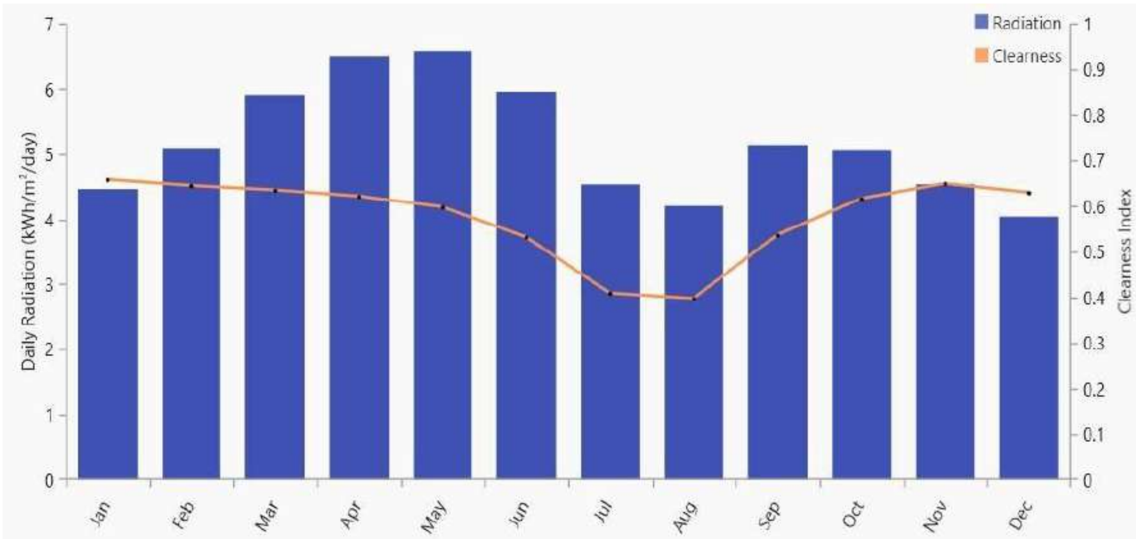

Fig. 5: Annual solar radiation within the study

4.0 TECHNO-ECONOMIC ANALYSIS FOR HYBRID SOLAR POWER SYSTEM

A detailed techno-economic analysis is undertaken to gauge the effectiveness and economic viability of the proposed hybrid solar power system configurations. Utilizing key metrics such as Levelized Cost of Energy (LCOE), Net Present Cost (NPC), and System PerformanceIndex (SPI), a comprehensive evaluation of both the technical and economic aspects of each configuration is conducted.

4.1 DESIGN PARAMETERS

The optimization of the Hybrid Solar Power Generation (HSPG) system adheres to HOMER design parameters, encompassing factors like Capital Cost, Replacement Cost, Operation and Maintenance Cost, and the lifespan of system components. Moreover, the study delves into macro-economic variables such as discount rate and inflation rate to ensure a thoroughtechno-economic analysis.

4.2 CRITERIA OF EVALUATION

4.2.1 Net Present Cost

The Net Present Cost (NPC) is an essential parameter for economic analysis, calculated by summing initial cost, replacement cost, and lifetime operation and maintenance cost. The net present cost assessed by equation (5) [8].

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

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 equation (6) [8].

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

The Capital Recovery Factor is the factor used to determine the present value of annual cash flows over a specified number of years (k) at a real interest rate (I_y) and expressed by equation (7) [8].

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

4.2.2 COST OF ENERGY

The cost of energy (COE) is the average per-unit cost of electricity over a renewable hybrid system's entire lifespan.

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

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 expressed by equation (8).

4.2.3 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 fromdiverse processes [8].

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

4.2.4 Renewable Penetration

Renewable Penetration (RP) is the percentage of energy derived from sustainable sources, calculated using equation (10) [8]. It quantifies the renewable fraction in a generation system, aiding in assessing the extent of energy obtained from environmentally friendly resources andguiding evaluations of the system's sustainability and environmental impact.

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

5.0 Design Optimization Parameters and Outcome

The research focuses on identifying the most cost-effective and efficient hybrid solar power system design for Udaipur. Optimization parameters include the sizing of solar panels, energystorage systems, and the integration of backup power sources. The goal is to achieve a balance between reliability, cost-effectiveness, and environmental sustainability.

5.1 SIMULATION REPORT OF GENERIC PV PLATE

Generic PV Plate of 36 kW is used in HSPV model. Simulation report of Generic PV Plate is shown in Table- 3 & 4, in which the total production is 59,247 kWh/year & levelized cost is 0.115$/kWh. **Fig. 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	6.76	kW
Mean Output	162	kWh/d
Capacity Factor	18.8	%
Total Production	59,247	kWh/year

Table 4: Simulation Report of Generic PV Plate

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	35.9	kW
PV Penetration	1,442	%
Hours of Operation	4,397	Hrs/year
Levelized Cost	0.115	$/kWh

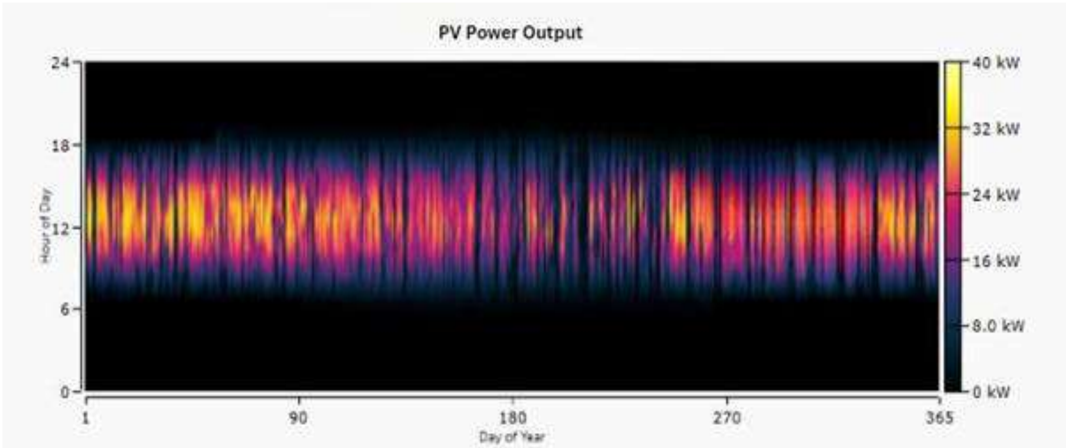

Fig.7: Simulation Result of PV Power Output

5.2 SIMULATION REPORT OF XANT M-21(100 KW) WIND TURBINE

XANT M-21 (100kW) wind turbine is selected for HSPV system. Simulation report of XANT M-21 (100kW) shown in Table- 5 & 6, in which the total production is 253,552 kWh/year. **Fig. 8** shows the Simulation result of XANT M-21 (100kW) wind Turbine.

Table 5: Simulation Report of XANT M-21 (100kW) Wind Turbine

Quantity	Value	Units
Total rated Capacity	100	kW
Mean Output	28.9	kW
Capacity Factor	28.9	%
Total production	253,552	kWh/year

Table 6: Simulation Report of XANT M-21 (100 kW) Wind Turbine

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	100	kW
Wind Presentation	6,170	%
Hours of Operation	7,216	hrs/year

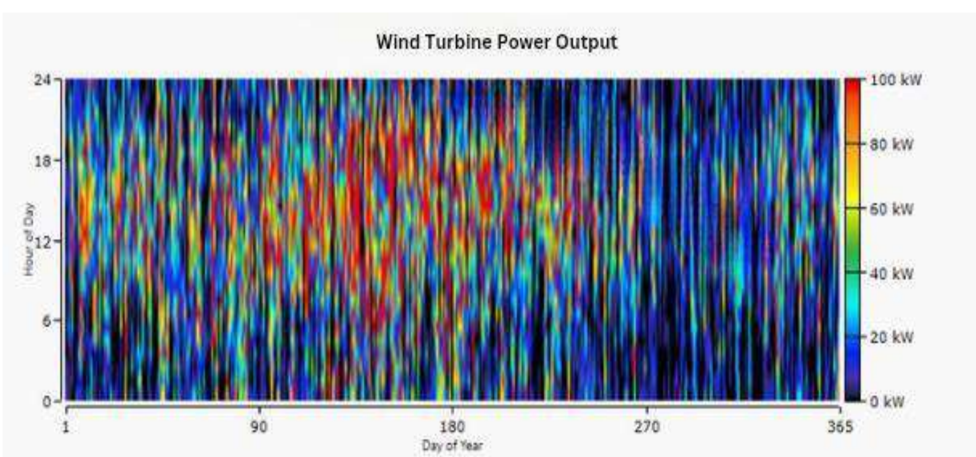

Fig. 8: Simulation Result of XANT M-21 (100kW) Wind Turbine

5.3 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 XANT M-21 (100 kW) wind turbine is 313,157 kWh/year. **Fig. 9** 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	59,247	18.9
XANT M-21 (100KW)	253,552	81.0
Grid Purchases	357	0.114
Total	313,157	100

Table 8: Simulation Report of Primary Load, Grid Sales and Total ElectricalEnergy Consumption

Consumption	kWh/year	%
AC Primary Load	4,109	1.31
Grid Sales	309,047	98.7
Total	313,157	100

Table 9: Simulation Report of Renewable Fraction and Max. RenewablePenetration

Quantity	Value	Units
Renewable Fraction	99.9	%
Max. Renewable Penetration	193,575	%

Fig. 9: Simulation Result of Total Electrical Energy Production

5.4 FINANCIAL REPORT

Table 10 shows the Simulation Result of Financial Report, in which total Net Present Cost (NPC) is $25,814,660.

Table 10: Simulation Result of Financial Report

Total Net Present Cost (NPC)	$25, 814, 660
Levelized Cost	$6.38
Operating Cost	$2,003,464

6.0 RESULTS AND DISCUSSION

The results of the simulations and analyses are presented and discussed in detail. Comparative evaluations of different system configurations highlight the trade-offs between performance, cost, and reliability. The findings contribute to the understanding of the optimaldesign parameters for hybrid solar power systems in Udaipur.

Case-I: Generic Flat Plate Setup vs. Integrated Generic Flat Plate Pv & Wind Turbine

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 and XANT M-21(100kW) wind turbine. **Fig. 10** shows the simulation result of Case-1, which shows that hybrid cost system (lowest cost system), saves money ($42 millions) over the project lifetime $50 millions (i.e., 84%).

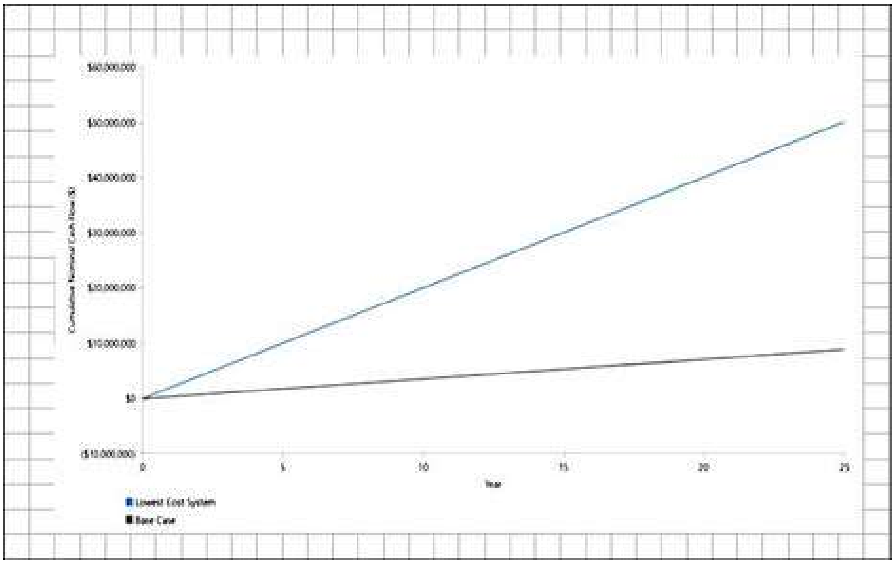

Fig. 10: Comparative cost benefits of Wind turbine and battery storage vs. Integrated GenericFlat Plate PV & Wind Turbine

Case-Ii: Wind Turbine and Battery Storage vs. Integrated Generic Flat Plate Pv & WindTurbine

In the Case-II; Base cost system uses XANT M-21 (100kW) wind turbine, converter 0.33kW and battery storage LI ASM 3.00 whereas lowest cost system uses Generic Flat Plate PV 36.0kW and XANT M-21(100kW) wind turbine. **Fig. 11** shows the simulation result of Case-II, which shows that hybrid cost system (lowest cost system), saves money ($8 millions) over the project lifetime $50 millions (i.e., 16%).

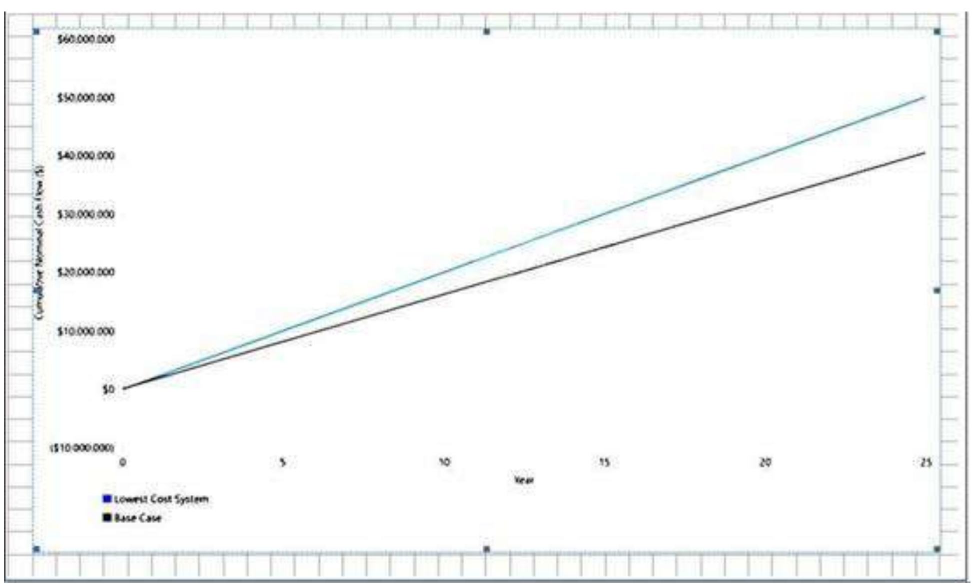

Fig. 11: Comparative cost benefits of Wind turbine and battery storage vs. Integrated GenericFlat Plate PV & Wind Turbine

Case-III: Wind turbine vs. Integrated Generic Flat Plate PV & Wind Turbine

In the Case-III; Base cost system uses XANT M-21 (100kW) wind turbine whereas lowest cost system uses Generic Flat Plate PV 36.0 kW and XANT M-21(100kW) wind turbine.**Fig. 12** shows the simulation result of case-III, which shows that hybrid cost system (lowest cost system), saves money ($15 millions) over the project lifetime $50 millions (i.e., 30%).

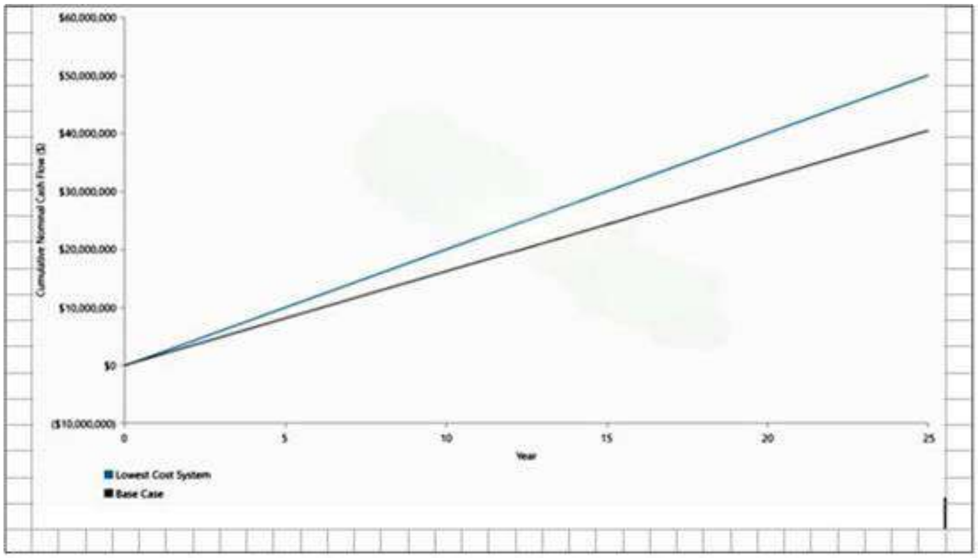

Fig. 12: Comparative cost benefits of Wind turbine vs. Integrated Generic Flat Plate PV & Wind Turbine

7.0 CONCLUSION

This paper concludes with a summary of the key findings, implications for the deployment of hybrid solar power systems in Udaipur, and recommendations for future research. The techno-economic analysis and design optimization presented in this study offer valuable insights for policymakers, energy planners, and researchers working towards sustainable energy solutions in regions with similar characteristics.

From the analysis of various options of systems, it provides valuable insights into the cost- effectiveness and performance of various hybrid solar power system configurations as given below:

- ***Generic Flat Plate Setup vs. Integrated Generic Flat Plate PV & Wind Turbine:*** When system employs a Generic Flat Plate PV 36.0 kW setup, while the lowest cost system integrates both Generic Flat Plate PV 36.0 kW and XANT M-21 (100kW) wind turbine, it is evident that the hybrid cost system (lowest cost system) proves to be economically advantageous over the project's lifetime. This underscores the potential savings ($42 millions) achievable through the integration of wind energy in hybrid systems (i.e., 84%).

- ***Wind turbine and battery storage vs. Integrated Generic Flat Plate PV & Wind Turbine:*** When the system incorporates XANT M-21 (100kW) wind turbine, converter 0.33kW, and battery storage LI ASM 3.00, compared to the lowest cost system utilizing both Generic Flat Plate PV 36.0 kW and XANT M-21 (100kW) wind turbine, it demonstrates the economic benefits associated with the hybrid cost system. Once again, the integration of wind energy plays a crucial role in cost savings ($8 millions) over the project's duration 25 years (i.e., 16%).

- ***Wind turbine vs. Integrated Generic Flat Plate PV & Wind Turbine:*** When the system relies solely on the XANT M-21 (100kW) wind turbine, compared to the lowest cost system incorporating both Generic Flat Plate PV 36.0 kW and XANT M-21 (100kW) wind turbine, it reiterates the financial advantages (of $15 millions) offered by the hybrid cost system. This reaffirms the importance of incorporating diverse renewable energy sources to enhance cost-effectiveness in hybrid solar power systems (i.e., 30%).

Thus, the results from all above mentioned systems underscore the economic viability and potential cost savings achievable through the integration of wind energy alongside solar power in hybrid systems. These findings emphasize the importance of considering hybrid configurations for sustainable and economically beneficial renewable energy solutions.

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