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Integration of PV and Diesel Generators for Off-Grid Power Systems: An Optimal Design Using HOMER Software

Divia Cheetu, Harpreet Kaur Channi*

Department of Electrical Engineering, Chandigarh University, Mohali 140413, Punjab, India.

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***Corresponding author:** Harpreet Kaur Channi, Department of Electrical Engineering, Chandigarh University, Mohali 140413, Punjab, India.

Abstract

This study presents the optimal design of a PV-diesel generator-based electricity system for the selected location in Kharar, Punjab, India. The system architecture consists of a generic 1kWh Lead Acid battery, a 10.2 kW flat plate PV system, a 4.69 kW System Converter, and an autosized 4.70 kW diesel generator. The analysis includes important metrics and results. The Total Net Present Cost (NPC) and the Levelized Cost of Electricity (COE) for the proposed system are not provided in the available information but are integral for evaluating the economic feasibility. The estimated Operating Cost is $65,209.06, and various cost components are categorized and analysed. The electrical production of the system is detailed, with an average electrical output of 1.94 kW and a capacity factor of 19.0%. The total annual production from the PV system is 16,989 kWh. The diesel generator's fuel consumption is measured at 20.5 L annually, with a specific fuel consumption of 0.297 L/kWh. This information is vital for assessing the sustainability and operational aspects of the system. The study evaluates the performance of the lead-acid batteries, indicating the string size and other technical specifications. The renewable penetration of the system is impressive, with 68.4% of the total capacity being renewable, and 99.6% of renewable production meeting the load. In conclusion, the presented design showcases the potential of a PV-diesel generator-based system in providing electricity in Kharar, Punjab, India. It demonstrates the feasibility of incorporating renewable energy sources alongside a diesel generator, highlighting the system's strong renewable penetration. Further economic evaluations and environmental considerations are required to make informed decisions regarding its implementation and sustainability.

Keywords

PV; NPC; LCOE; renewable penetration; feasibility

1. Introduction

India possesses a substantial abundance of renewable energy resources and has achieved noteworthy advancements in effectively utilising these environmentally sustainable sources of power. Based on data sourced from the Ministry of New & Renewable Energy, India's global ranking in installed renewable energy capacity stands at fourth place. During the year 2020-2021, 'the nation successfully included a significant amount of 5.5 GW of wind power into its overall energy portfolio. This exemplifies an increasing dedication to shifting away from conventional fossil fuels towards cleaner and more ecologically sustainable energy alternatives. The scope of renewable energy sources in India comprises a diverse range of possibilities, such as photovoltaic (PV) solar, wind, hydro, and geothermal energy. These sources provide not just economically efficient alternatives but also substantial environmental advantages. The integration of photovoltaic (PV) and wind technologies, commonly known as a hybrid PV-Wind system, has become increasingly prominent in areas characterised by ample sunlight and strong wind conditions [1]. Hybrid systems of this nature have the capacity to augment the economic and ecological viability of non-conventional energy sources, thereby making a valuable contribution towards mitigating greenhouse gas emissions, which are widely recognised as a primary catalyst for the phenomenon of global warming.

Notwithstanding these technological breakthroughs, the present rate of growth in electricity generation in India is insufficient to adequately satisfy the rising energy requirements. The lack of sufficient resources is particularly evident in rural regions, where the availability of consistent electricity remains a significant obstacle. In response to the grid's inherent instability, diesel generators and batteries have been implemented as supplementary power sources in both business and residential contexts.' Nevertheless, despite the presence of these auxiliary systems, rural regions persist in encountering electrical deficiencies, particularly during peak demand periods. Solar energy represents a potentially viable alternative for mitigating energy deficiencies by providing a method for generating electricity in geographically isolated regions. Solar energy can be effectively captured during daylight hours, and any excess energy can be stored for further utilisation, thereby establishing a dependable and consistent energy supply. Nevertheless, the efficacy of renewable energy sources such as solar power is constrained by substantial upfront investment expenses and the intermittent nature of energy generation, stemming from variables such as weather patterns and diurnal fluctuations. Hybrid renewable energy systems, which integrate solar and wind energy sources, have emerged as a viable approach to tackle the difficulties. Solar energy generation is a suitable complement to wind power due to the distinct temporal patterns of electricity production. Solar panels are capable of generating electricity during daylight hours, whilst wind turbines effectively harness energy during the nighttime. The amalgamation of these factors yields a more uniform and economically efficient provision of energy [2].

The utilisation of HOMER software is crucial in the modelling and optimisation of hybrid renewable energy systems, facilitating the development of highly efficient and economically feasible configurations. In several geographical areas characterised by uncertain availability of renewable resources, the integration of a renewable energy source with a diesel generator function as a dependable contingency measure. Diesel generators are utilised in situations where solar energy generation is limited, such as on overcast days. This serves to maintain a consistent power supply and decrease dependence on fossil fuels. This strategy not only ensures the continuous provision of energy but also mitigates the release of harmful petrol emissions [20]. The HOMER Pro software programme assumes a significant function within this particular-context since it facilitates the design and assessment of micro-power systems, regardless of whether they operate off-grid or on-grid. The selection of the most efficient system design considers several elements, including cost, environmental impact, and technical criteria [3].

The incorporation of renewable energy in conjunction with backup alternatives such as diesel generators exhibits considerable potential in solving India's energy requirements, particularly in geographically isolated and inadequately supplied regions. "This study centres on the design and analysis of a specific system located in Kharar, Punjab, India, with a particular emphasis on the significance of renewable energy in attaining a power supply that is both sustainable and dependable. Nonetheless, it is imperative to conduct a thorough economic evaluation and environmental assessment in order to make educated judgements on the implementation and long-term viability of the system. The incorporation of renewable energy sources alongside backup systems not only improves the dependability of energy supply but also corresponds with India's overarching objectives for sustainability and decreased dependence on fossil fuels [4]. The integration of clean and renewable energy sources, such as solar and wind power, alongside supplementary assistance from diesel generators, has significant promise in effectively tackling the energy-related issues faced by the country.

As urbanisation progresses in India and energy requirements escalate, the significance of discovering inventive and ecologically conscientious solutions becomes progressively evident. The utilisation of the HOMER Pro software enables the examination of optimal configurations and system designs that effectively reconcile economic viability, environmental advantages, and technical efficacy. This study centres on the instance of Kharar, a region located in Punjab, India, and showcases the potential of a system that combines photovoltaic (PV) technology with a diesel engine. Nevertheless, it is vital to bear in mind that every place possesses distinct energy demands, resource accessibility, and environmental circumstances. Hence, it is imperative to acknowledge that although this study provides valuable insights, the incorporation of localised evaluations and adjustments is crucial for the effective execution of the proposed approach. In summary, the incorporation of sustainable energy sources, complemented with dependable alternatives such as diesel generators, signifies a progressive approach towards tackling India's energy-related obstacles. The approach possesses the capacity to facilitate the provision of electricity to geographically isolated and marginalised areas, hence mitigating the disparity in energy accessibility and fostering the principles of sustainability [5]. However, to fully harness the capabilities of these systems, it is imperative to conduct a thorough assessment that considers both economic and environmental aspects. This analysis highlights the importance of these initiatives and sets the stage for a future that is more sustainable and resilient in terms of energy security, not only in India but also in other regions.

2. Review of Literature

Muskan and Kaur Channi, H. discussed that the increasing global demand for energy and the finite nature of conventional fossil fuels have prompted a shift towards renewable energy sources [6]. This research explores the feasibility of a hybrid PV and diesel generator system, concluding that an optimal solution entails components costing $16,157, 1.98 kW PV arrays, and a 1.40 kW diesel generator, with a levelized Cost of Electricity (COE) at $0.4280. Additionally, the study introduces the application of silicon nanoparticles to enhance solar cells, reflecting advancements in solar technology. The research emphasizes the challenges faced by remote villages due to their limited access to centralized power stations, highlighting the need for localized and sustainable energy solutions. The future of Hybrid Renewable Energy Systems (HRES) is promising, with expanding applications and opportunities to address energy challenges [6]. Ali Saleh Aziz et al. analyzed an off-grid PV/diesel/battery hybrid energy system (HES) for a remote region in Iraq. Their results favored the suggested method over the default cycle charging (CC) strategy, showcasing an NPC of $4.03 million, a renewable portion of 41.3%, and annual CO2 emissions of 851,377 kg [7].

Reza Babaei et al. focused on a techno-economic feasibility study for the Western side of Pelee Island, Canada, with a daily load of 2,426 kWh. Various scenarios, including hybrid systems involving diesel (DG), wind (WT), and solar (PV) energy production linked with converters (CNV) and distinct battery-electric storage systems, were explored [7].

Barun K. Das conducted a comprehensive techno-economic analysis comparing standalone and grid-integrated PV/Wind/Diesel/Battery hybrid energy systems (HES) across five climate zones [8]. Kumar, R., and Channi, H. K. investigated the photovoltaic (PV)/biomass energy potential for Sidhwanbet, Punjab, India, using HOMER Pro v3.14 software to model a hybrid renewable energy system (HRES) designed to supply constant energy for 770 homes [9]. Ling Ji et al. reported on the ideal design and technological viability of a hybrid energy system for Suifenhe, Northeast China, using a mixed-integer linear programming model to compare cost-effectiveness and environmental advantages between standalone and grid-connected modes [10]. Kumar, A., and Verma, A. emphasized the shift towards renewable energy sources due to concerns about fossil fuel electricity production and the common use of diesel generator sets (DG-sets) as backup power sources [11]. In another study, Abd El-Sattar et al. (2021) proposed three distinct hybrid system configurations merging a biomass system with photovoltaic (PV), wind turbine (WT), and battery systems. These research contributions address various aspects of hybrid energy systems and their viability [12]. The problem formulation for the optimal designing of a PV-diesel generator-based system using HOMER software involves determining the most cost-effective and environmentally sustainable configuration. It requires addressing variables such as site-specific conditions, load profiles, generator sizing, energy storage, and grid interaction, while ensuring reliability, minimizing fossil fuel usage, and complying with regulations. The main goal of this research is given below:

- Determine the most cost-effective configuration by minimizing capital and operational expenses, including solar panel costs, energy storage, and fuel consumption, while maximizing the system's economic viability.
- Ensure a reliable power supply by appropriately sizing the diesel generator, and incorporating energy storage for load balancing.

3. Methodology

The study begins by providing a solid foundation for the research and identifies knowledge gaps and areas of improvement. Next, data collection and system parameterization are performed, including geographical location, solar irradiance, load profiles, and economic data. The optimization process involves running simulations and sensitivity analyses to find the most cost-effective and sustainable design that minimizes the reliance on diesel generators. Performance metrics like Levelized Cost of Energy (LCOE), Net Present Value (NPV), and environmental impacts are evaluated to assess the system's economic and environmental sustainability.

3.1 Site Details

The HRES (Hybrid Renewable Energy System) Pre-Feasibility Estimation for the selected location at 9789, New Swaraj Nagar, Kharar, Punjab, 140301, Kharar, India (Postal Code: 140301) is a vital step in assessing the potential for implementing a sustainable and efficient energy solution in this specific geographical area. Kharar, a rapidly developing city in the state of Punjab, India, is the site of interest for this pre-feasibility estimation. The geographical coordinates of this location offer promising prospects for harnessing renewable energy as shown in Figure 1 [13]. Its altitude above sea level, prevailing climate conditions, and solar irradiance levels provide a unique set of parameters that contribute to the assessment of renewable energy potential. In the coming stages of this pre-feasibility estimation, we will delve into a detailed analysis of the location's energy demand, renewable energy potential, system components required, economic feasibility, environmental impact, and associated risks. By thoroughly evaluating these factors, we aim to provide informed recommendations regarding the feasibility of implementing an HRES in this specific area. This study not only holds the promise of reducing the environmental impact but also the potential to provide a sustainable and reliable energy supply to the community in and around New Swaraj Nagar, Kharar, Punjab, India.

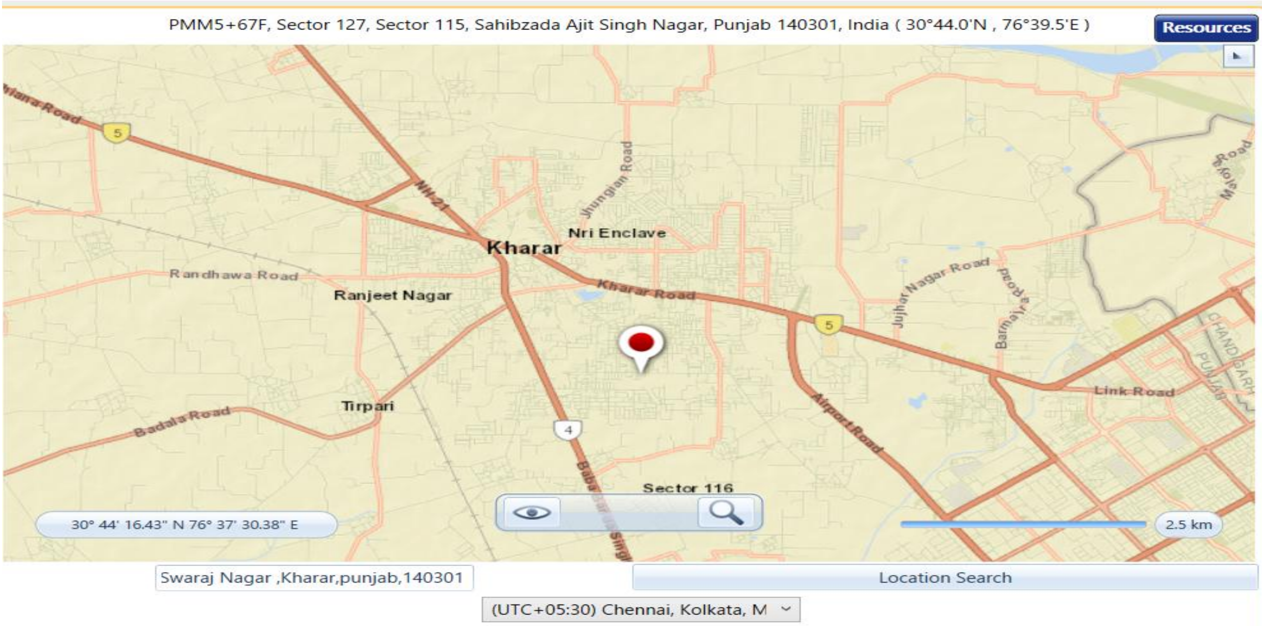

Figure 1. Selected location.

3.2 Load Calculation

In this section load of various months is taken from January to December. In January load is around 1.5kW, February is having load of around 1.4kW, March having 1.75kW, April, May and June are having load of 1.9kW. The month of July is having load of 2.4kW, August is having load around 2.2kW, September is having around 2.1kW, October is having load around 1.8kW, November is having load around 1.9kW and December is having load around 1.4kW. Average home load is taken as 20 kWh/day with 4.25 kW peak as shown in Figure 2.

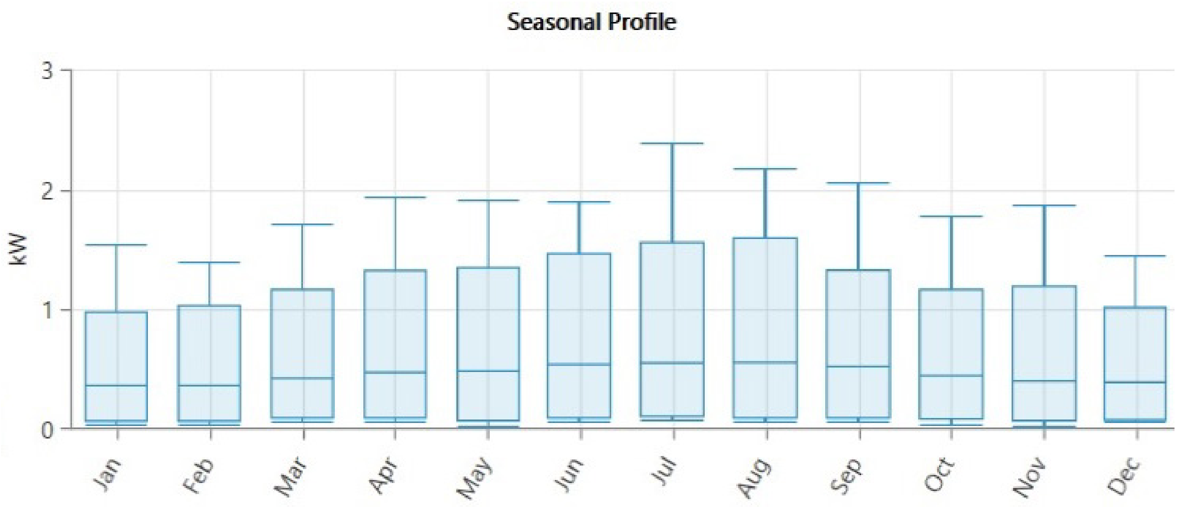

Figure 2. Seasonal Profile.

3.3 Designing and Modelling

3.3.1 System Layout

The methodology of this study considers several key components to model the system effectively. These components include solar photovoltaic (PV) systems, rechargeable battery storage systems, and a diesel generator for backup. In Figure 3, the proposed configurations illustrate the system's structure, where the electrical load is in the form of AC, the solar PV system is integrated into a DC connection, the diesel engine source is connected to an AC connection, and the battery is linked with a DC-link. Each of these components plays a crucial role in ensuring a reliable and sustainable power supply.

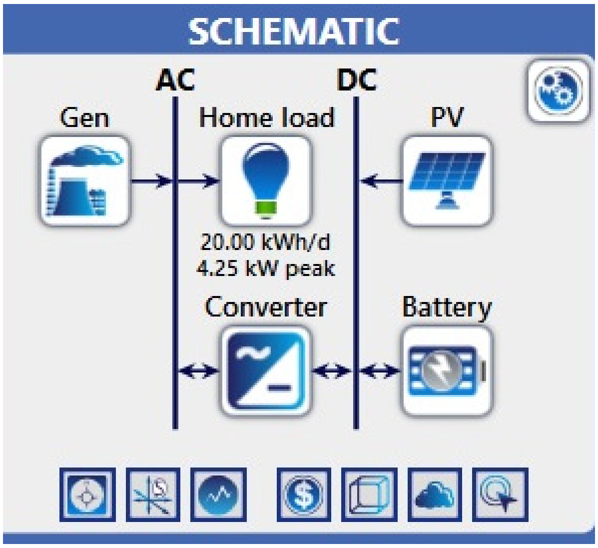

Figure 3. Schematic Components.

- **Solar: PV**

The solar PV system, in conjunction with the other components, contributes to the overall generation of electrical energy from solar irradiance. It operates during daylight hours, converting sunlight into electricity, and any surplus energy generated can be stored in rechargeable batteries for use during periods when solar energy is unavailable, ensuring a continuous power supply. The cost factors and performance metrics associated with the generic flat plate PV system are crucial in the economic and technical evaluation of the entire energy system. The key specification of PV is shown in Table 1. The D-map of Solar PV is shown in Figure 4.

Table 1. Solar PV Specifications

Name	Generic Flat Plate PV
Panel	Flat plate
Rated Capacity	10.2 kW
Cost and Investment	
Capital Cost	$2,500.00
Lifetime	35 years
Replacement Cost	$2,500.00
Operational and Maintenance (O&M) Cost	$1.00/year
Total Production	16,989 Kwh/yr
Performance Metrics	
Derating Factor	80.00%
Minimum Output	0 kW
Maximum Output	10.3 kW
PV penetration	233%
Hours Of Operation	4,374 hrs/yr
Levelized Cost	3.47 Rs. /kWH
Clipped Production	0 kWH
Mean Output	1.94 kW
Mean Output	46.5 kWh/day
Capacity Factor	19.0%

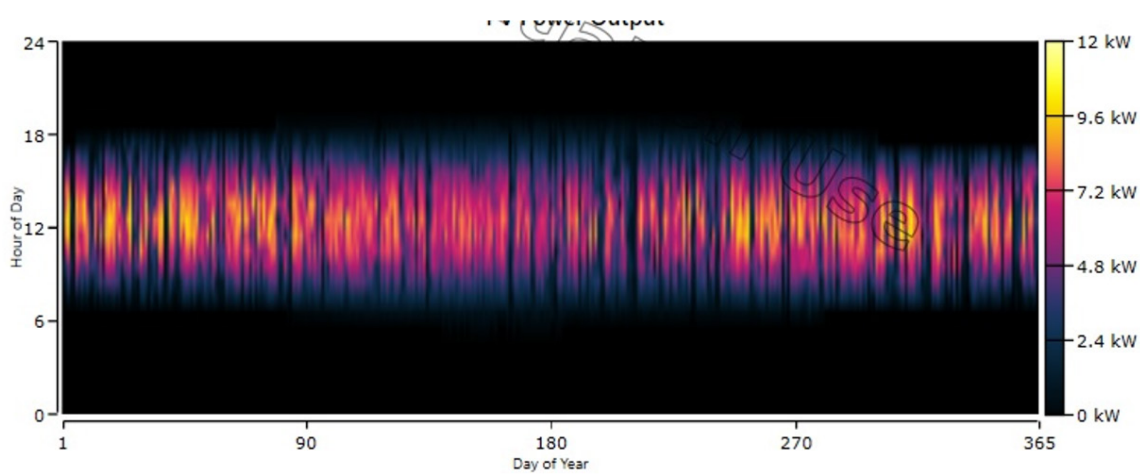

Figure 4. D-map of Solar PV.

- **Converter**

The system converter, with its pivotal role in the energy system, plays a significant part in managing the flow of electricity, ensuring compatibility between different components, and optimizing the performance of the entire system. In this study, a generic system converter is employed for these purposes. The key specification of the converter is shown in Table 2.

Table 2. Converter Specification

Key properties	
Name	System Converter
Manufacturer	Generic
Cost and Investment	
Capital Cost	$39,600.00
Lifetime	20 years
Replacement Cost	$15,000.00
Operational and Maintenance Cost	$500.00/year
Performance Metrics	
Relative Capacity	81.20%
Input Efficiency	95.00%
Output Efficiency	98.00%

The converter is in Parallel with the AC generator: (Indicates whether the converter operates in parallel with an AC generator, enhancing system reliability and efficiency) The system converter facilitates the energy flow within the system by converting and adapting electricity from different sources, ensuring that it aligns with the needs of the load. Its efficiency metrics and relative capacity are crucial in evaluating how effectively it manages energy conversion and distribution within the system.

- **Diesel generator**

The generator, often a vital component in hybrid energy systems, provides backup power generation when other renewable sources such as solar PV are unavailable. In this study, an auto-sizing generator is employed to meet the electrical load demand during periods of low renewable energy generation. The specifications of the Diesel generator are in Table 3.

Table 3. Diesel Generator Specifications

Key Properties	
Name	Autosize Genset
Cost and Investment	
Initial Capital	$50,000.00
Lifetime	15,000 hours
Replacement Cost	$25,000.00
Operational and Maintenance (O&M) Cost	$90.00 per operating hour
Fuel Price	$400.00 per litre
Fuel Details	
Fuel Type	Diesel
Fuel Curve Intercept	0.263 L/hr
Fuel Curve Slope	0.236 L/hr per kW
Total Fuel Consumed	20.5 L
Average Fuel Per day	0.0562 L/day
Average Fuel Per hour	0.0234 L/hour

Table 3 Continued

Emissions	
Emission of CO (Carbon Monoxide)	16.5 g/L fuel
Emission of Unburned HC (Hydrocarbons)	0.72 g/L fuel
Emission of Particulates	0.1 g/L fuel
Emisssion of Fuel Sulphur to PM	2.2%
Emission of NOx (Nitrogen Oxides)	15.5 g/L fuel
Operation and Maintenance	
Minimum Load Ratio	35.00%
Lifetime Hours	15,000 hours

The generator is connected to the AC electrical bus. The generator serves as a reliable source of electricity when solar or other renewable sources are insufficient. Its auto-sizing capability ensures it can meet the required load. The choice of diesel as fuel and the associated emission data are essential for assessing the environmental impact of the generator's operation. Additionally, understanding the cost structure, fuel efficiency, and maintenance requirements is critical in evaluating its feasibility within the hybrid energy system.

- **Battery**

Energy storage plays a pivotal role in the stability and reliability of hybrid energy systems, such as the one analysed in this study. The system utilizes a lead-acid battery to store excess electricity and release it when needed, effectively managing energy supply and demand. The specifications of the battery are shown in Table 4. The state of charge of the battery is shown in Figure 5.

Table 4. Battery Specifications

Key Properties	
Name	Generic 1kWh Lead Acid
Battery Specifications	
Nominal Voltage	12 V
Nominal Capacity	1 kWh
Maximum Capacity	83.4 Ah
Capacity Ratio	0.403
Rate Constant	0.827 per hour
Roundtrip Efficiency	80%
Maximum Charge Current	16.7 A
Maximum Discharge Current	24.3 A
Maximum Charge Rate	1 A/Ah
Batteries	42.0 qty.
String Size	42.0
Autonomy	40.4 hr
Nominal Capacity	42.0 kWh
Energy In	4,946 kWh/yr

Table 4 Continued

Energy Out	3,941 kWh/yr
Usable Nominal Capacity	33.6 kWh
Lifetime Throughput	29,400 kWh
Losses	987 kWh/yr
Annual Throughput	4,406 kWh/yr
Cost and Investment	
Capital Cost	$7,500.00
Lifetime	10 years
Replacement Cost	$2,500.00
Operational and Maintenance (O&M) Cost	$500.00 per year
Average Energy Cost	€0.700/kWh
Storage Wear Cost	€3.99/kWh
Site-Specific Information	
String Size	1
Initial State of Charge	30.00%
Minimum State of Charge	20.00%
Minimum Storage Life	5.00 years

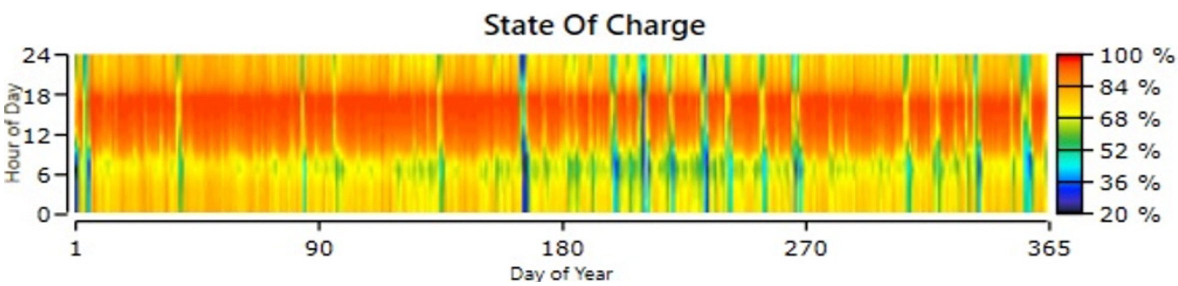

Figure 5. State Of Charge of Battery.

The lead-acid battery provides critical energy storage capacity, allowing the system to store surplus energy during periods of excess generation and discharge it when demand exceeds supply. The battery's efficiency, capacity, and charging/discharging capabilities are essential in maintaining a stable energy supply. Additionally, the cost structure and maintenance requirements contribute to the overall feasibility and cost-effectiveness of the hybrid energy system.

3.4 Economic Analysis

This economic analysis demonstrates the financial advantages of the proposed system, showcasing significantly reduced costs, higher efficiency, and an exceptionally short payback period [14, 15]. The drastic reduction in the Levelized COE further supports the economic viability of transitioning to the proposed PV-diesel generator-based hybrid energy system, highlighting its potential to provide sustainable and cost-effective electricity generation for the region as shown in Table 5.

- **Net Present Cost (NPC)**

The Net Present Cost (NPC) is a financial metric that represents the total cost of a system over its lifetime, accounting for both capital and operating expenses. It can be calculated using the equation 1.

$$NPC=CAPEX+\sum t=1n(1+r)tOPEXt+FC \quad (1)$$

➢ **Levelized Cost of Electricity (COE)**

The Levelized Cost of Electricity (COE) is a key metric for assessing the cost of electricity generation over the lifetime of a system. It represents the per-unit cost of electricity produced and can be calculated as equation 2.

$$COE=\sum t=1nEtNPC \quad (2)$$

➢ **Operating Costs**

Operating costs represent the annual expenses incurred to operate and maintain the system. They include items like maintenance, fuel, and other operational expenses. These costs are calculated using Equation 3.

$$OPEXt=\sum i\mathrm{Cost}i \quad (3)$$

Table 5. Economic Metrics Comparison

Metric System	Base System	Proposed System
Total NPC ($)	$221million	$235,000
Levelized COE ($)	$24.82	$1.50
Annual Worth ($/yr)	$16.89 million	$1.50 million
Return on Investment (%)	1,340	High
Internal Rate of Return applicable(n/a)	Not applicable	Not applicable
Simple Payback(years)	0.07	Very short (0.07)
Discounted Payback(years)	0.08	Very short (0.08)

Categorization of cost components involves classifying expenses into different categories to gain insights into which aspects contribute most to the overall cost. This categorization can be done by type (e.g., capital, maintenance, fuel) or by specific cost items as shown in Table 6.

Table 6. Cost Summary

Capital Costs	
Autosize Genset	$235,000
Generic 1kWh Lead Acid	$315,000
Generic flat plate PV	$763,575.29
System Converter	$185,558.40
Operating Costs	
Autosize Genset	$235,000
Generic 1kWh Lead Acid	$315,000
Generic flat plate PV	$763,575.29
System Converter	$22,408.10
Fuel Costs	
Autosize Genset	$0.00
Generic 1kWh Lead Acid	$763,575.29
Generic flat plate PV	$0.00
Salvage	$23,860.83
Other Costs	$48,144.47

3.4.1 Renewable Fraction

The renewable fraction measures the proportion of electricity generated from renewable sources, such as the photovoltaic (PV) system, in relation to the total electricity generated. In this simulation, the renewable fraction is 99.1%, indicating that the majority of electricity is derived from the renewable PV system. Max. renewable penetration represents the maximum percentage of the total electrical load that can be met by renewable energy sources like the PV system. In this scenario, it is recorded as 3,145%, suggesting that the PV system has a considerable surplus in comparison to the electrical load and can potentially contribute to powering additional loads or storing excess energy.

These metrics are critical in evaluating the performance of the system, especially when considering the integration of renewable energy sources like the PV system. Understanding factors like excess electricity and renewable penetration can help optimize energy generation, storage, and consumption strategies. It's essential for making informed decisions to improve system efficiency and sustainability.

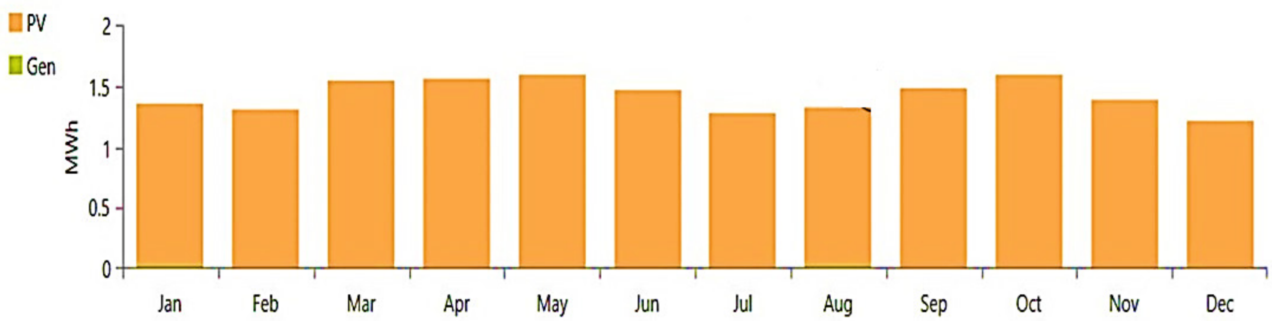

Figure 6. Renewable Fraction.

4. Results and Discussions

Table 7 indicates component wise cost of the system. This categorization allows for a detailed analysis of the contribution of different cost components to the overall expenses. The capital column indicates the initial capital cost in Indian Rupees (Rs.) for each component. The initial cost of Autosize Genset is Rs. 2,35,000.00, Generic 1Kwh lead acid is Rs. 3,15,000.00, Generic Flat plate PV is Rs.7,63,575.29, System Converter is Rs.1,85,558.40. The total initial Capital cost for the entire system is Rs. 1,499,133.69. The Replacement Cost is highest in Generic 1Kwh lead Acid and lowest in Autosize Genset and Generic Flat plate PV. The operation and maintenance cost is highest in Autosize Genset and lowest in Generic Flat plate PV. The Fuel costs are highest in the case of Autosize Genset and lowest for the rest. The salvage Costs are highest in Generic Flat plate PV and lowest in the case of Autosize Genset. The total cost for the entire system is Rs. 2,342,124.85.

Table 7. Components Wise Costs Summary

Component	Capital (Rs.)	Replacement (Rs.)	O&M(Rs.)	Fuel (Rs.)	Salvage (Rs.)	Total (Rs.)
Autosize Genset	2,35,000.00	0.00	3,88,859.70	23860.83	-27,397.43	6,20,323.10
Generic 1Kwh Lead Acid	3,15,000.00	1,54,109.54	271,477.85	0.00	-6,376.53	7,34,210.86
Generic Flat plate PV	763,575.29	0.00	131.60	0.00	-1742.10	761,964.79
System Converter	185,558.40	22,408.10	30,288.01	0.00	-12,628.40	2,25,626.11
SYSTEM	1,499,133.69	176,517.64	690,757.16	23860.83	-48,144.47	2,342,124.85

The simulation results presented in this analysis offer a comprehensive insight into the performance and economics of a complex energy system. This system, comprising components such as a Generic 1kWh Lead Acid battery, Generic flat-plate PV, System Converter, and an Autosize Genset, represents a microcosm of contemporary energy infrastructure. These results provide a thorough evaluation of the system's capabilities, efficiency, and financial aspects.

The key parameters include metrics like Total NPC (Net Present Cost), Levelized COE (Cost of Electricity), Operating Costs, and a Categorization of Cost Components. They reflect the financial implications and sustainability of this energy setup. Additionally, the analysis explores the electrical production of the system, encompassing metrics like Average Electrical Output, Capacity Factor, and Annual Production from the PV system as shown in Table 8. These metrics reveal how efficiently the system generates and utilizes electrical energy. Further details include the system's fuel consumption, with specifics on Diesel Generator Fuel Usage and Specific Fuel Consumption. These metrics are essential in understanding the operational aspects and sustainability of the system, especially concerning fuel utilization and efficiency.

Table 8. Simulation Result

Parameter	Value
Total NPC	€2,342,125.00
Levelized COE	€24.82
Operating Cost	€65,209.06

- Total NPC (Net Present Cost): The Total NPC represents the total financial cost associated with the system. In this case, the Total NPC is €2,342,125.00. It accounts for all the expenses incurred over the lifetime of the system, including initial investment and operational costs.
- Levelized COE (Cost of Electricity): The Levelized COE is a measure of the cost per unit of electricity produced by the system. In this analysis, the Levelized COE is €24.82, indicating the average cost of generating one unit of electricity.
- Operating Cost: The Operating Cost reflects the expenses accrued during the operation of the energy system. For this particular system, the Operating Cost amounts to €65,209.06. It includes costs associated with maintenance, fuel, and other operational aspects.

Table 8 provides valuable insights into the financial aspects of the energy system, offering an understanding of the overall cost, cost per unit of electricity, and operational expenses. These metrics are crucial for financial planning, investment decisions, and assessing the economic viability of the system.

Overall, this analysis provides a robust foundation for assessing the system's performance and suitability for various applications, ranging from off-grid power supply to grid-tied renewable energy generation. The results offer a comprehensive picture of the economic, operational, and environmental aspects of the system, allowing for informed decision-making and policy formulation in the field of energy management and sustainability. In this section, we conduct a comprehensive analysis of the economic aspects of the proposed system. The economic performance is critical in evaluating the feasibility and viability of the PV-diesel generator-based hybrid energy system. We compare the base system consisting of Generic 1kWh Lead Acid batteries, 10.2 kW Generic flat-plate PV, 4.70 kW Autosize Genset, and 4.69 kW System Converter to the proposed system featuring 1.50 MW of PV capacity.

5. Conclusion

Designing an optimal PV-diesel generator-based system using HOMER software is a multifaceted task that necessitates a holistic approach. This system's success hinges on meticulous consideration of various crucial elements. First and foremost, site-specific characteristics, such as solar irradiance, climate conditions, and load profiles, must be accurately incorporated into the design. The integration of photovoltaic (PV) panels plays a pivotal role in reducing reliance on diesel generators and promoting the efficient use of solar energy during daylight hours. Energy storage systems, like batteries, are essential for balancing energy supply and demand, enabling excess solar energy to be stored for later use, thereby diminishing diesel generator dependence. Optimal sizing of the diesel generator is vital to match peak loads and serve as a reliable backup. A comprehensive cost analysis, encompassing capital expenditures, maintenance, and fuel costs, is fundamental for identifying the most cost-effective solution over the system's lifecycle. The system architecture consists of a generic 1kWh Lead Acid battery, a 10.2 kW flat plate PV system, a 4.69 kW System Converter, and an autosized 4.70 kW diesel generator. The analysis includes important metrics and results. The Total Net Present Cost (NPC) and the Levelized Cost of Electricity (COE) for the proposed system are not provided in the available information but are integral for evaluating the economic feasibility. The estimated Operating Cost is $65,209.06, and various cost components are categorized and analysed. The electrical production of the system is detailed, with an average electrical output of 1.94 kW and a capacity factor of 19.0%. The renewable penetration of the system is impressive, with 68.4% of the total capacity being renewable, and 99.6% of renewable production meeting the load.

Furthermore, grid interaction should be considered for either grid support or selling excess power, enhancing economic feasibility. Environmental considerations underscore the need to reduce greenhouse gas emissions and assess the ecological benefits of the system. Reliability, redundancy, lifecycle analysis, regulatory compliance, and incentives are additional critical aspects to ensure the long-term success of the PV-diesel system. In conclusion, the optimal design of a PV-diesel generator-based system using HOMER software is a multidimensional undertaking that seeks to maximize efficiency, reduce costs, and align with sustainability objectives. Regular monitoring and adherence to regulations are imperative to maintain the system's long-term performance and contribute to a cleaner and more sustainable energy future.

5.1 Implications and Future Research

The implications of this study extend beyond the specific PV-diesel generator system analysed. Our findings offer valuable insights into the design and operation of hybrid energy systems that incorporate renewable sources and fossil fuel-based generators. These insights are particularly relevant in regions where grid instability or lack of access to a reliable power grid necessitates hybrid solutions.

Future research in this domain should focus on optimizing the system for further reduction in environmental impact and operating costs. This could involve improving energy storage systems to enhance renewable energy utilization and reduce reliance on diesel generators. Additionally, exploring the integration of advanced technologies, such as energy storage and demand-side management, can contribute to more sustainable and cost-effective solutions.

In conclusion, the PV-diesel generator system demonstrates strong potential as a feasible and sustainable energy solution with a high renewable penetration rate. This study underscores the importance of integrated renewable energy systems and offers a foundation for further research and innovation in the field of clean energy production and distribution.

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