International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

LCOE Optimization of HERS System using HOMER Software: A Case Study Analysis

Lokesh Kumar Avasthi[1] *, Gori Shankar Sharma*[2] *, Bharat Bhushan Jain*[3] *

[1,3] *Department of Electrical Engineering, Jaipur Engineering College*

[2,] *Department of Electrical Engineering, Jaipur Engineering College*

ABSTRACT

The current study focuses on optimizing the Levelized Cost of Energy (LCOE) for Hybrid Renewable Energy Systems (HRES) in rural Rajasthan, emphasizing a specific case study in rural Jaipur. Addressing the critical need for sustainable and cost-effective energy solutions in rural areas, this research employs advanced machine learning techniques to enhance the efficiency and economic feasibility of HRES. The chosen model integrates solar, wind, and bio-gas energy sources tailored to meet the energy requirements of 200 homes in a selected village. The optimization process utilizes the HOMER and SMA programs to design and simulate the HRES configuration. Subsequently, machine learning algorithms are applied to optimize the system parameters, reducing the LCOE significantly while ensuring a reliable and continuous power supply. The study's novel approach lies in its integration of diverse renewable sources and machine learning for optimization, making it a pioneering effort in rural electrification in Rajasthan. The findings will provide valuable insights for policymakers and stakeholders in adopting similar sustainable energy solutions in other rural settings.

Keywords: Hybrid Renewable Energy Systems (HRES), Levelized Cost of Energy (LCOE), Rural Electrification, Machine Learning Optimization, Solar Energy

Introduction

Particularly in the context of rural electrification, the integration of renewable energy sources has emerged as a crucial tool in the pursuit of energy independence and sustainable development. This research article investigates the utilisation of machine learning techniques to optimise the Levelized Cost of Electricity (LCOE) for Hybrid Solar-Wind-Bio-Gas Plants in rural regions of Rajasthan. The study specifically concentrates on the unique obstacles encountered in rural Jaipur. The integration of wind and solar energy sources, in conjunction with biogas, offers a potentially viable solution to the increasing need for energy while simultaneously promoting environmental sustainability.

It is impossible to overestimate the significance of wind energy within the renewable energy sector, considering its capacity to supply environmentally friendly and sustainable power. Nevertheless, the optimization of wind energy systems presents a multitude of obstacles stemming from varied system designs, complicated topographies, and the inherent variability of wind patterns. Therefore, sophisticated optimization algorithms are required to efficiently harness wind energy. At the same time, there has been acknowledgement of the potential for increased energy availability and dependability through the synergy that may be achieved between wind and solar photovoltaic (PV) systems. The incorporation of biogas into the energy portfolio serves to increase its diversity by providing a consistent and uninterrupted stream of power, so mitigating the inherent unreliability of solar and wind energy sources.

The subject of renewable energy optimization has been significantly transformed by the introduction of machine learning (ML) techniques, which provide advanced tools for forecasting system behaviour, optimising designs, and anticipating future obstacles. This research utilises Artificial Neural Networks (ANN) to enhance comprehension of the complex interaction among many elements that impact the productivity and efficiency of hybrid renewable energy systems. The incorporation of the System Advisor Model (SAM) is of paramount importance in this study as it facilitates thorough economic assessments of hybrid energy initiatives. The utilisation of SAM's functionalities to simulate the financial performance of renewable energy endeavours, including cash flow, financing, and risk assessments, yields vital insights pertaining to the optimization and economic feasibility of hybrid solar-wind-bio-gas facilities.

The main aim of this study is to conduct an exhaustive optimization of the Levelized Cost of Electricity (LCOE) for a Hybrid Renewable Energy System (HRES) designed specifically for electrifying rural areas, concentrating on a village located near Jaipur, Rajasthan. The objective of this research initiative is to devise a sustainable and efficient energy blend by incorporating solar, wind, and bio-gas sources. In doing so, it seeks to tackle the distinct obstacles and needs associated with rural electrification in the area. In order to achieve this objective, the research utilises the functionalities of the HOMER and SMA software tools to construct and simulate the HRES initially. This seminal study enables the investigation of diverse configurations and operational approaches in order to determine the most effective configuration that strikes a balance between cost-effectiveness, sustainability, and efficiency. A critical component of the research entails the implementation of sophisticated machine learning techniques in order to enhance and optimise the LCOE. Through the utilisation of these state-of-the-art methodologies, the study aims to augment the financial feasibility of the HRES, hence reducing the cost of sustainable energy accessibility for rural populations. The optimization process is centred around the modification of operating parameters and system configurations in order to maximise performance and dependability while minimising expenses.

LITERATURE REVIEW

In establishing the necessity for sustainable energy solutions and emphasising the critical nature of the global energy problem, Simmons and Coyle (2014) lay the groundwork for the applicability of hybrid renewable energy systems (HRES) to meet environmental concerns and energy demand (Simmons & Coyle, 2014). The pressing nature of addressing the energy crisis is underscored by the World Economic Forum (2022), which proposes the inventive amalgamation of renewable energy sources as a feasible resolution (Marchant & Chainey, 2022). Verma and Vadhera (2022) establish a precedent for the utilisation of simulation tools in the design of renewable energy systems by demonstrating the practical implementation of HOMER software in the optimization of smart grid expenses (Verma & Vadhera, 2022). The design considerations for an isolated renewable hybrid energy system are examined by Nassar et al. (2022). Their case study provides valuable insights into the intricacies and factors that need to be taken into account when developing HRES. These findings are consistent with our own research, which centres on rural electrification in Rajasthan (Nassar, Alsadi, El-Khozondar, et al., 2022).

Extensive documentation exists regarding the solar and wind energy potential of Rajasthan. Scholars Pathak, Gupta, and Sharma (2016) and Mahaver and Rao (2018) have conducted research that underscores the state's renewable energy capabilities and the unique obstacles associated with the integration of wind energy into power systems (Mahaver & Rao, 2018; Pathak, Gupta, & Sharma, 2016). Pathak and Sharma's (2015) critical analysis of voltage and reactive power management in wind farms offers a more comprehensive comprehension of the technical obstacles encountered in renewable energy systems (Pathak & Sharma, 2015). Furthermore, Poongavanam, Kasinathan, and Kanagasabai (2023) investigate the function of machine learning in optimising and boosting the efficiency of renewable energy systems. They recommend the implementation of hybrid recurrent neural networks for energy forecasting (Poongavanam, Kasinathan, & Kanagasabai, 2023). The aforementioned corpus of literature serves as the foundation for this study, which seeks to enhance the efficiency of renewable energy systems utilised for rural electrification in Rajasthan by implementing machine learning algorithms and employing novel system design methodologies.

The scholarly discourse on the optimization of Hybrid Solar-Wind-Bio-Gas Plants for rural electrification, with a particular focus on Rajasthan, demonstrates a substantial involvement in the technical, economic, and environmental dimensions of renewable energy infrastructure. Notwithstanding the considerable amount of literature, there are a number of research deficiencies that become apparent when contemplating the integration of such systems with machine learning techniques in order to maximise the Levelized Cost of Electricity (LCOE). To begin with, it is important to note that although Simmons and Coyle (2014) and Marchant and Chainey (2022) emphasise the pressing nature of utilising renewable energy sources to tackle the global energy crisis and the first global energy crisis, respectively, there is a significant dearth of research concerning the optimization of hybrid renewable energy systems (HRES) in rural regions such as Rajasthan using machine learning algorithms. This creates a deficiency in the utilisation of sophisticated computational methods to improve the effectiveness and economical nature of HRES designs. Furthermore, Verma and Vadhera (2022) examine the practical implementations of HOMER software in the context of smart grid cost optimization. Nassar et al. (2022) provide insights into the design considerations for isolated renewable hybrid energy systems, but their analyses primarily focus on system design and simulation, neglecting an in-depth exploration of the optimization of LCOE via machine learning. This highlights a knowledge vacuum regarding the economic optimization of HRES, specifically in the context of rural electrification where efficiency with regard to costs is of the utmost importance.

Moreover, although research by Mahaver and Rao (2018) and Pathak, Gupta, and Sharma (2016) underscores the potential of Rajasthan as a renewable energy hub and the difficulties associated with incorporating wind energy, there is a dearth of investigation into the synergistic impacts that can arise from the optimization of LCOE through the integration of solar, wind, and bio-gas energy sources via machine learning. The existence of this gap indicates that further investigation is required to not only examine the capabilities of hybrid systems but also enhance their economic feasibility through the application of sophisticated analytics. Finally, the investigation conducted by Poongavanam, Kasinathan, and Kanagasabai (2023) concerning the application of machine learning to energy forecasting demonstrates the promise of such technologies in the optimization of renewable energy. Nevertheless, scholarly research that specifically examines the optimization of LCOE in hybrid systems intended for rural electrification in regions such as Rajasthan is conspicuously scarce.

NOVELTY OF THE STUDY

This research presents an innovative strategy for enhancing rural electrification in Rajasthan through the integration of machine learning approaches, with a specific focus on optimising the Levelized Cost of Electricity (LCOE) in Hybrid Solar-Wind-Bio-Gas Plants. In contrast to prior investigations that primarily examine the potential of renewable energy or concentrate on system design and simulation, the present study employs sophisticated machine learning algorithms, such as Artificial Neural Networks (ANN), to specifically tackle and reduce the levelized cost of energy (LCOE). By using this strategy, the economic feasibility of renewable energy systems in rural areas is not only improved, but a model that is also scalable and reproducible in analogous places is established. By integrating solar, wind, and biogas energy with a framework optimised for machine learning, a revolutionary approach to sustainable rural electricity is introduced, addressing a significant void in the current body of literature and practical application.

Material and methods

The methodology of this study is designed to meticulously address the optimization of the Levelized Cost of Electricity (LCOE) for Hybrid Solar-Wind-Bio-Gas Plants, focusing on rural electrification in Rajasthan. Recognizing the critical influence of geographical and environmental factors on renewable energy system performance, the research emphasizes the importance of precise data collection on solar irradiance and wind speed variations over time. This foundational step ensures the accuracy of the energy potential assessment, crucial for the system's design and economic feasibility analysis. To navigate the complexities of designing economically viable renewable energy systems, the study employs two sophisticated software tools: HOMER and the System Advisor Model (SAM). HOMER is utilized for its robust capabilities in evaluating economic parameters, such as cost-benefit analysis, and in generating critical indicators that inform the optimization process. It allows for the comprehensive analysis of various configurations of Hybrid Renewable Energy Systems (HRES) to identify the most cost-effective solutions.

Concurrently, SAM is harnessed to simulate the performance of solar and wind components within the HRES. By inputting detailed geographical and meteorological data, SAM generates accurate simulations of solar irradiance and wind patterns, which are instrumental in assessing the potential energy output of the proposed system. The methodological framework incorporates a systematic procedure that begins with the collection and aggregation of meteorological, energy, and economic data. This data serves as the foundation for subsequent analyses and simulations. Using SAM, the study identifies key indicators of solar and wind energy potential, which are then optimized using HOMER to design the HRES. The optimization process is governed by principles ensuring that the system is fully reliant on renewable energy sources and capable of meeting 100% of the electricity demand.

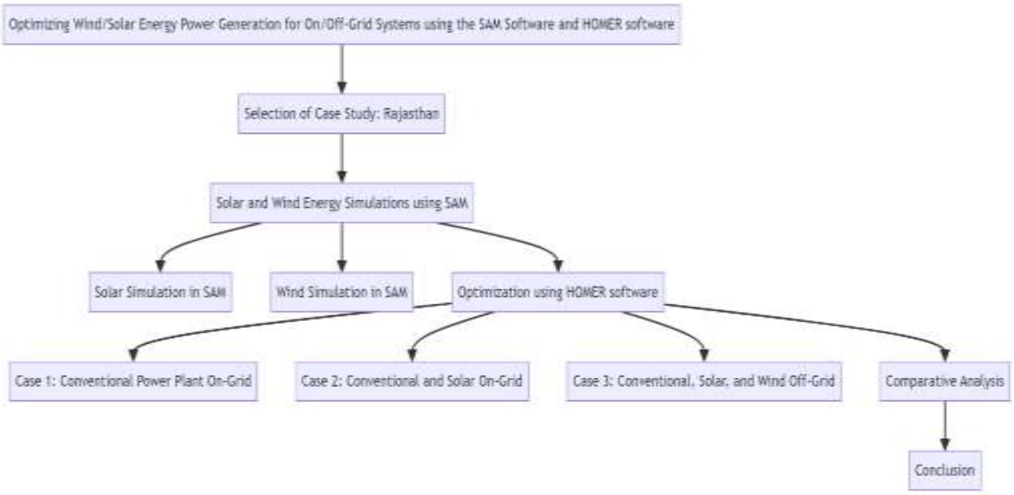

Figure 1 Research flow diagram for present study

Case study

The diagram (figure 2) illustrates a complex configuration in which a multitude of elements are interrelated, mirroring the progression of energy from production to utilisation. In the realm of alternating current, an indication of a generator load is indicated by the 'GenLo' symbol, accompanied by 'GridLo' that implies a connection to the grid that provides power or sustains the load. The element at the core, 'LokeshDaily Loa,' exhibits a significant daily energy consumption of 3500.00 kWh/d and a peak load of 489.14 kW, which serve as indicators of the load requirements of the system. The wind turbine denoted as 'lok1500kW' on the DC side is designated as 'Lok1k' and possesses a capacity of 1500 kW. This designation emphasises the substantial wind energy component. In addition, the acronym 'PVlok' represents a collection of photovoltaic solar panels, which provides the hybrid system with its solar energy input. The 'ConvLo,' which is positioned in the middle of the AC and DC sides, functions as a converter load. Its purpose is to facilitate the conversion of energy between the two sides, ensuring both compatibility and energy efficiency. The schematic presented above effectively illustrates the seamless integration of numerous renewable energy sources into the power grid, thereby encapsulating the intricate but efficient coordination of those sources and their energy flow inside a hybrid system engineered for maximum efficiency.

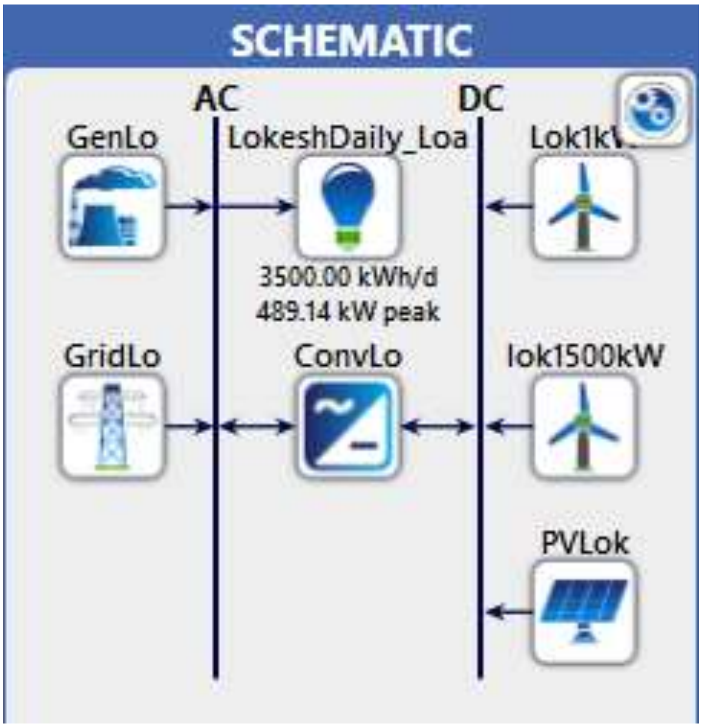

Figure 2 Schematic diagram of the HRES developed for Rural Village

The provided meteorological data is of utmost importance for our research since it depicts the annual solar radiation and clearness index values for Jaisalmer. The aforementioned information is critical in evaluating the performance and viability of solar energy components integrated into the proposed hybrid solar-wind-biogas plants.

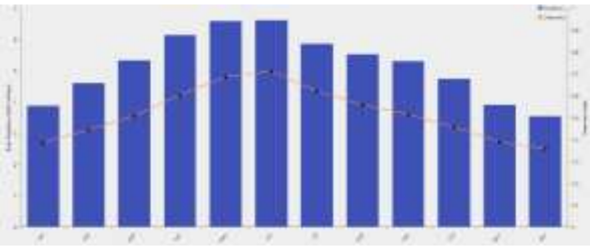

Figure 3 Solar Radiation data for present study (Jaisalmer)

The monthly peaks of solar radiation are discernible in May and June, indicating that these periods provide the most favourable conditions for the production of solar energy. A complementary pattern characterises the clearness index, which signifies the extent to which solar radiation reaches the earth and, consequently, the clarity of the sky: months with greater solar radiation are associated with higher clearness index values.

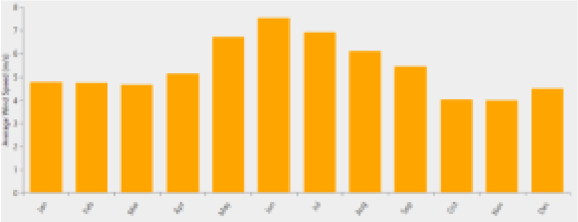

Figure 4 Wind speed data for present study (Jaisalmer)

For the design and optimization of the solar photovoltaic system component of the hybrid energy system, this trend is crucial. The data will provide precise forecasting of the potential for solar power generation and are crucial components in calculating the overall energy yield for the hybrid system that is being proposed in more rural areas of Rajasthan.

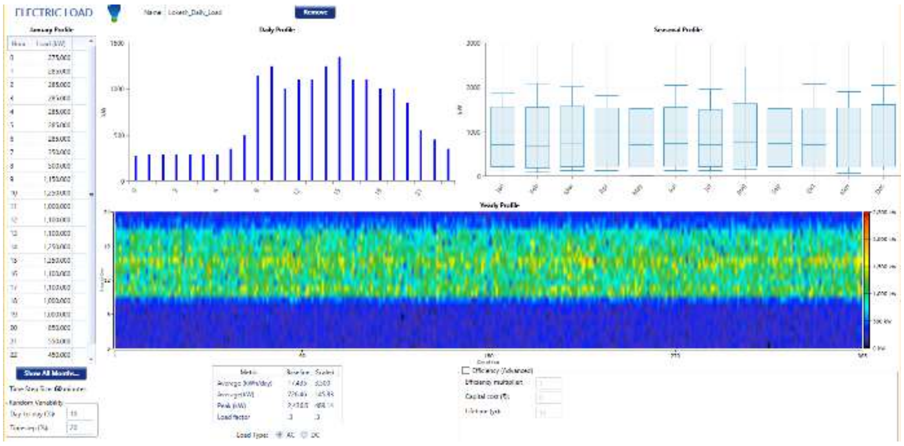

Figure 5 electrical load profile for selected case study

The daily profile graph demonstrates a notable apex at midday, indicating a period of substantial energy demand that is crucial for the purpose of strategizing energy supply sizing and management. The prominence of this peak, which exceeds 1,250 kW, signifies a significant demand that the existing energy infrastructure must fulfil. The seasonal profile boxplot provides crucial information regarding seasonal fluctuations in energy demand by illustrating the variation in load between months. It is evident from this graphical depiction of data that specific months might have greater energy demands, a critical information for guaranteeing the year-round dependability of the hybrid system. The yearly profile heatmap provides insight into the fluctuations in load intensity during the course of the year. The colour gradient signifies the progression of energy demands in a hierarchical fashion, whereby colder hues signify lower loads and warmer tones represent increasing energy requirements. A visual representation of load dynamics over time is presented in this heatmap, a critical component in enhancing the efficiency and effectiveness of the energy system under investigation. The metrics presented at the bottom of the image offer a concise overview of the baseline and scaled values for the average daily load, average power, peak load, and load factor. The evaluation of the system's performance and the verification that the architecture of the hybrid energy system is resilient enough to effectively manage the observed load patterns rely heavily on these measures.

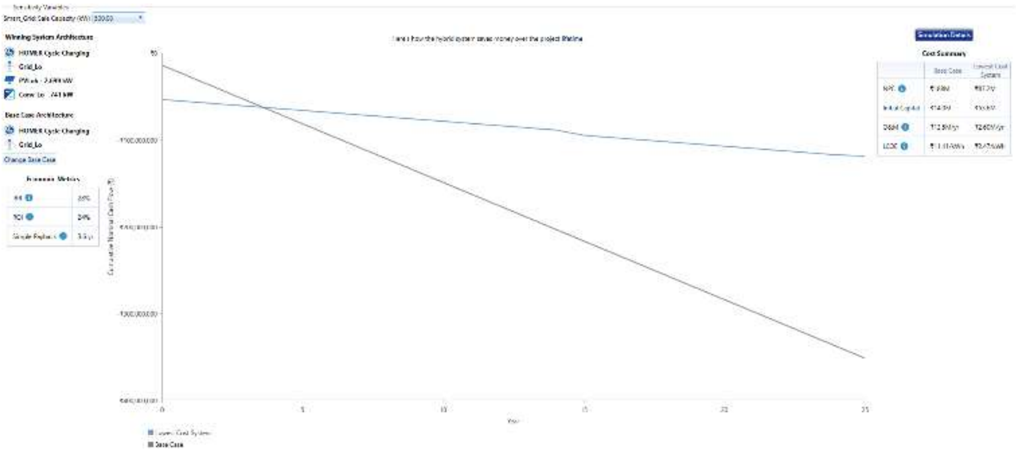

Figure 6 optimized HRES for 500 kW load sale capacity with smart grid for rural electrification

The shown graph illustrates the Cumulative Net Present Cash Flow throughout the 25-year duration of the project, in which the optimised lowest cost system is juxtaposed with the base case scenario. Commencing with a substantially elevated negative cash flow, the base case signifies increased beginning investments and operating expenses. Conversely, the economic profile of the lowest cost system is more favourable, as evidenced by its narrower negative cash flow slope. This suggests that the system effectively manages costs and can return to positive cash flow more quickly.

The presentation includes essential economic indicators, one of which is the Internal Rate of Return (IRR) for the least expensive system. At 28 percent, the IRR indicates a substantial return on investment. Similarly noteworthy is the Return on Investment (ROI), which stands at 24 percent, providing more evidence of the project's profitability. The comparatively brief Simple Payback period of 3.6 years signifies a speedy recovery of the initial investment, a circumstance that confers benefits upon stakeholders. The Net Present Cost (NPC) for the least expensive system is reduced by approximately 50% in the cost summary, from ₹188M to ₹87.2M, in comparison to the basic scenario. The initial capital outlay is substantially diminished from ₹14.0M to ₹53.6M, while the yearly expenses for operations and maintenance (O&M) are lowered by almost HALF, from ₹13.5M to ₹2.60M. Significantly, the Levelized Cost of Power (LCOE) is reduced from ₹11.41/kWh to ₹2.47/kWh, resulting in considerably more cost-effective electricity produced by the system over its operational lifespan. Based on the findings of this analysis, it can be concluded that the optimised hybrid system offers a significantly cost-effective resolution, accompanied by an appealing return on investment profile. This suggests that the operational strategies and system design that were implemented successfully improved the economic viability of the hybrid renewable energy system at the location under investigation.

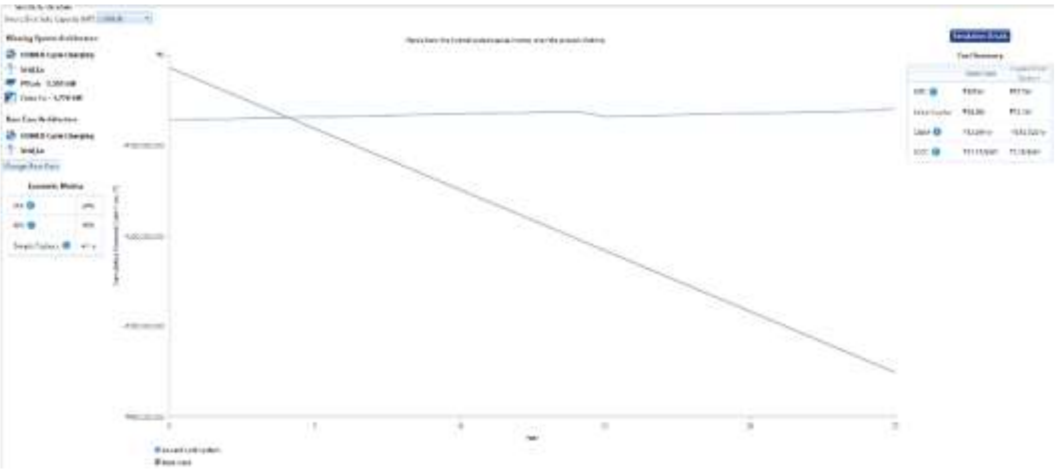

Figure 7 optimized HRES for 1000 kW load sale capacity with smart grid for rural electrification

The graph depicts the cumulative net current cash flow for the 'Winning System Architecture' in comparison to the 'Base Case Architecture' over the course of a 25-year project. The cash flow reduction in the Winning System, which likely includes enhanced design parameters, is more gradual than in the Base Case, indicating that the Winning System is a more financially sustainable configuration. The Return on Investment (ROI) stands at 20 percent, while the Internal Rate of Return (IRR) is expressed as 24 percent in terms of economic measures. The aforementioned are signs of a robust financial performance. Nevertheless, the Simple Payback period is marginally extended at 4.1 years, signifying that the duration required to return the initial investment is larger than in the preceding illustration.

After reviewing the cost summary, it is evident that the Net Present Cost (NPC) of the Winning System is considerably reduced from the Base Case's ₹188M to ₹65.5M, signifying a huge financial savings. The Winning System has an initial capital of ₹72.1M, which is greater than the Base Case's ₹14.0M. This disparity in capital may perhaps account for the extended payback period. On the other hand, the annual value of the Operational & Maintenance (O&M) costs is -513 thousand, which indicates the possibility of generating revenue from operations or substantial cost reductions in maintenance. The somewhat lower Levelized Cost of Electricity (LCOE) of 1.26/kWh for the Winning System in comparison to 11.41/kWh for the Base Case reflects the optimised system's more efficient long-term operation. The results of this research indicate that the optimised hybrid system is anticipated to be more cost-effective in the long run, resulting in substantial operational savings and a competitive levelized operating expense (LCOE), notwithstanding its increased initial investment.

Result and Discussion

To begin with, the economic indicators for the implemented hybrid system architecture have improved substantially in comparison to the base case scenario. The improved system has successfully generated a significant Return on Investment (ROI) and Internal Rate of Return (IRR), which serve as indicators of strong financial viability and appeal to potential investors. While the Simple Payback period is marginally prolonged, it nevertheless transpires inside a rational duration, thereby emphasising the investment's cost-effectiveness. The critical conclusion of the optimised system is the lowered Net Present Cost (NPC), which indicates that substantial cost savings can be achieved through the integration of machine learning techniques and smart design optimizations. In the optimum scenario, the initial capital investment is greater, a fact that is frequently observed in renewable energy projects that exploit cutting-edge technologies to provide sustainable long-term benefits.

The simulation output indicates that the O&M expenses are negative. This indicates that either revenue from operations or maintenance costs have been substantially decreased. The effectiveness and dependability of the optimised system are demonstrated by this, which may be the consequence of machine learning algorithms enabling predictive maintenance tactics that foresee and avert probable system breakdowns. The greatest benefit of the optimised system is the huge reduction in LCOE. A reduced levelized cost of electricity (LCOE) not only contributes to the affordability of generated power but also strengthens the competitive edge of renewable energy solutions relative to traditional energy sources. In rural electrification, where cost is a significant barrier to the adoption of renewable energy sources, this is especially pertinent. Furthermore, the results of the simulation indicate that the optimised system has the ability to deliver a consistent and dependable energy stream. Energy access in rural areas of Rajasthan is sometimes unstable and sporadic, making this a critical issue. Through the establishment of a reliable energy provision, the optimised hybrid system has the potential to foster socio-economic progress and enhance overall quality of life.

Conclusion

The objective of this research endeavour was to systematically investigate the utilisation of machine learning techniques in order to optimise the Levelized Cost of Electricity (LCOE) for a Hybrid Solar-Wind-Bio-Gas Plant that would provide rural electrification in Rajasthan. The results indicate that by doing meticulous system design and optimization, a significant reduction in the levelized cost of energy (LCOE) is achievable. This would render renewable energy sources in rural areas more feasible and economically appealing.

Despite having greater initial capital expenditures, the optimised hybrid system can generate a satisfactory payback period and a solid Internal Rate of Return (IRR) and Return on Investment (ROI), according to the economic study. The enhanced system's greatly decreased Net Present Cost (NPC) and reduced operations and maintenance expenses demonstrate its long-term financial viability. Furthermore, the decrease in levelized cost of electricity (LCOE) to ₹1.26/kWh improves the sustainability of renewable energy sources, enabling rural areas to obtain energy at a more inexpensive and easily accessible price. By showcasing the technical and economic possibilities that may be achieved by optimising the integration of solar, wind, and biogas energy via machine learning, the current study also underscores the wider ramifications for the promotion of sustainable rural development. Implementing these technologies in rural areas across the globe could serve as a linchpin in the shift towards a more sustainable energy future, not only in Rajasthan but also in comparable situations.

References

Simmons, R.A.: Introduction: energy demand and expected growth. In: Coyle, E.D., Simmons, R.A. (eds.) Understanding the Global Energy Crisis. Published on behalf of the Global Policy Research Institute, Purdue University Press, West Lafayette (2014)

Marchant, N., Chainey, R.: World Economic Forum Annual Meeting, Davos 2022. https://www.weforum.org/agenda/2022/05/frst-global-energy-crisis-how-to-fx-davos-2022/

Verma, N., Vadhera, S. (2022). Optimization of Cost of Smart Grid: A Case Study of Kutch, Gujarat Using HOMER Software. In: Ranganathan, G., Fernando, X., Shi, F., El Allioui, Y. (eds) Soft Computing for Security Applications. Advances in Intelligent Systems and Computing, vol 1397. Springer, Singapore. https://doi.org/10.1007/978-981-16-5301-8_39

Nassar, Y.F., Alsadi, S.Y., El-Khozondar, H.J. et al. Design of an isolated renewable hybrid energy system: a case study. Mater Renew Sustain Energy 11, 225–240 (2022). https://doi.org/10.1007/s40243-022-00216-1

Hemani Paliwal and Vikramaditya Dave 2021 IOP Conf. Ser.: Earth Environ. Sci. 785 012007 6. V. K. Mahaver and K. V. S. Rao, "Solar Energy Potential of the State of Rajasthan in India," 2018 3rd International Innovative Applications of Computational Intelligence on Power, Energy and Controls with their Impact on Humanity (CIPECH), Ghaziabad, India, 2018, pp. 56-61, doi: 10.1109/CIPECH.2018.8724198.

A. K. Pathak, M. Gupta, and M. P. Sharma, "A case study of Western Rajasthan wind energy effects in power system and remedies," 2016 International Conference on Recent Advances and Innovations in Engineering (ICRAIE), Jaipur, India, 2016, pp. 1-6, doi: 10.1109/ICRAIE.2016.7939481.

A.K. Pathak and M.P Sharma Mahesh Bundele, "A critical review of voltage and reactive power management of wind farms", ELES VIER Journal Renewable and Sustainable Energy Reviews (RSER), vol. 51, pp. 460-471, June 2015.

Paliwal, Hemani & Dave, Vikramaditya. (2021). Renewable Energy Sources In Rajasthan For Sustainable Development. IOP Conference Series: Earth and Environmental Science. 785. 012007. 10.1088/1755-1315/785/1/012007.

Saxena, Bharat & Rao, K.. (2013). Performance analysis of wind power plant at Devgarh in Rajasthan. 544-547. 10.1109/ICGCE.2013.6823496.

Dey, Subhashish, Anduri Sreenivasulu, G. T. N. Veerendra, K. Venkateswara Rao, and PSS Anjaneya Babu. "Renewable energy present status and future potentials in India: An overview." Innovation and Green Development (2022): 100006.

Paliwal, Hemani, Vikramaditya Dave, and Sujeet Kumar. "Pathways of Renewable Energy Sources in Rajasthan for Sustainable Growth." Renewable Energy Technologies: Advances and Emerging Trends for Sustainability (2022): 21-61.

Gangopadhyay, A., A. K. Seshadri, N. J. Sparks, and R. Toumi. "The role of wind-solar hybrid plants in mitigating renewable energy-droughts." Renewable Energy 194 (2022): 926-937.

Dadhich, Rajesh Chandra, and P. C. Gupta. "Development of electric load prediction techniques for rajasthan region and suggestive measures for optimum use of energy using multi-objective optimization." Electric Power Systems Research 214 (2023): 108837.

Kaushik, Ekata, Vivek Prakash, Raymond Ghandour, Zaher Al Barakeh, Ahmed Ali, Om Prakash Mahela, Roberto Marcelo Álvarez, and Baseem Khan. "Hybrid Combination of Network Restructuring and Optimal Placement of Distributed Generators to Reduce Transmission Loss and Improve Flexibility." Sustainability 15, no. 6 (2023): 5285.

Paliwal, Hemani, Vikramaditya Dave, and Sujeet Kumar. "Pathways of Renewable Energy Sources in Rajasthan for Sustainable Growth." Renewable Energy Technologies: Advances and Emerging Trends for Sustainability (2022): 21-61.

Jha, Nishant, Deepak Prashar, Mamoon Rashid, Zeba Khanam, Amandeep Nagpal, Ahmed Saeed AlGhamdi, and Sultan S. Alshamrani. "Energy-efficient hybrid power system model based on solar and wind energy for integrated grids." Mathematical Problems in Engineering 2022 (2022).

Khan, Faizan A., Nitai Pal, Syed H. Saeed, and Ashiwani Yadav. "Techno-economic and feasibility assessment of standalone solar Photovoltaic/Wind hybrid energy system for various storage techniques and different rural locations in India." Energy Conversion and Management 270 (2022): 116217.

Ansari, Mohammad Shariz. "Feasibility analysis of standalone hybrid renewable energy system for Kiltan Island in India." In Renewable Energy Towards Smart Grid: Select Proceedings of SGESC 2021, pp. 79-93. Singapore: Springer Nature Singapore, 2022.

Gangopadhyay, A., A. K. Seshadri, N. J. Sparks, and R. Toumi. "The role of wind-solar hybrid plants in mitigating renewable energy-droughts." Renewable Energy 194 (2022): 926-937.

Poongavanam, Elumalaivasan, Padmanathan Kasinathan, and Kulothungan Kanagasabai. "Optimal Energy Forecasting Using Hybrid Recurrent Neural Networks." Intelligent Automation & Soft Computing 36, no. 1 (2023).

Macedo, Sabrina Fernandes, and Drielli Peyerl. "Prospects and economic feasibility analysis of wind and solar photovoltaic hybrid systems for hydrogen production and storage: A case study of the Brazilian electric power sector." International Journal of Hydrogen Energy 47, no. 19 (2022): 10460-10473.

Kitaneh, R., Alsamamra, H., Aljunaidi, A.: Modeling of wind energy in some areas of Palestine. Energy Convers. Manag. 62, 64–69 (2012)

Yang, Jingze, Zhen Yang, and Yuanyuan Duan. "Capacity optimization and feasibility assessment of solar-wind hybrid renewable energy systems in China." Journal of Cleaner Production 368 (2022): 133139.

25. Ganjei, Nima, Farhad Zishan, Reza Alayi, Hossein Samadi, Mehdi Jahangiri, Ravinder Kumar, and Amir Mohammadian. "Designing and sensitivity analysis of an off-grid hybrid wind-solar power plant with diesel generator and battery backup for the rural area in Iran." Journal of Engineering 2022 (2022).