Review Paper

INTERNATIONAL JOURNAL OF CURRENT ADVANCED RESEARCH
ISSN: O: 2319-6475, ISSN: P: 2319-6505
Available Online at www.journalijcar.org
Volume 14; Issue 04; April 2025; Page No.154-161
DOI: http://dx.doi.org/10.24327/ijcar.2025.161.0035

Subject Area : Science and Engineering

A COMPREHENSIVE REVIEW ON THE DESIGN AND OPTIMIZATION OF SOLAR-WIND HYBRID POWER SYSTEMS

Mahendra Kumar[1], Alok Kumar Singh[2] and Shiv Lal[3]

[1,2]School of Engineering and Technology, Nirwan University Jaipur, Rajasthan
[3]Department of Renewable Energy, Rajasthan Technical University, Kota, Rajasthan

ARTICLE INFO

Received 15th March 2024
Received in revised form 22nd March, 2024
Accepted 17th April, 2025
Published online 28th April, 2025

Key words:

Power Quality, Solar-Wind Hybrid System, Web Integration, Harmonic Destruction, Tension Stability, Power Electronics, Energy Sto

ABSTRACT

Integration into the power grid in renewable energy sources such as sun and wind has increased significantly in recent years. However, these hybrid systems introduce electrical quality problems, including voltage -fast rash, harmonic deformities and frequency deviations. This review papers examine recent trends and technologies to improve the power quality of the solar and wind Hybrid Energy Systems. Different power conditioning techniques, control strategies and mitigation methods are analyzed to increase online stability and performance. The study concludes that superior electricity electronics, machine studying -based manipulate mechanisms and a robust strength storage device play an essential role in enhancing the strength high-quality of renewable structures. This article offers a complete overview of the layout and optimization of solar-wind hybrid energy systems, overlaying numerous crucial factors to provide a well-rounded understanding of the problem. It starts an introduction outlining the importance and potential of hybrid renewable power solutions, accompanied by way of a review of Previous Research highlighting key contributions and improvements in the discipline. The section on Solar-Wind Basics gives the essential ideas and complementary nature of sun and wind strength sources. Further, the item consists of quick yet crucial records at the Designing Components for Solar-Wind Hybrid Power Systems, discussing major hardware factors which includes photovoltaic panels, wind mills, batteries, and converters. Control Strategies are explored to give an explanation for the strategies used for efficient power control and load balancing. In Design Optimization, various techniques and algorithms hired to decorate device overall performance and reduce prices are reviewed. The article also examines Simulation Tools typically used for device modeling and evaluation. A phase on Economic Analysis evaluates the financial feasibility and fee-effectiveness of hybrid structures. It additionally addresses present Challenges

INTRODUCTION

The energy demand is increasing day by day proportional to increasing the population and technological advancements and industrialization. The assessment of demand side management can help to predict the energy sources integration of solar, wind, ESS, and other technologies [1, 2]. The solar PV can be used for power generation for both stand alone and grid integration. The standalone PV systems mostly used at the places where grid is not available or for agricultural purposes [3, 4]. The feasibility of solar wind integration for a particular area has an important aspect towards the green energy for buildings [5]. Solar-Wind Hybrid Power Systems are incorporated renewable electricity solutions that integrate the usage of solar photovoltaic (PV) panels and wind generators to generate energy. These systems are designed to capitalize at the complementary nature of solar and wind electricity assets-solar electricity is typically greater to be had all through sunny sunlight hours hours, even as wind power is regularly more considerable at night time or throughout cloudy and stormy climate. By combining each assets, hybrid systems ensure a greater reliable and non-stop energy supply in comparison to standalone solar or wind systems. The design and optimization studies have been carried out by various researchers [6] and its important to realise and how to improve the power quality with solar PV and wind integration using various techniques like FACTS devices. Kumar [2024] et al studied the power quality enhancement in grid connected Solar Wind hybrid system using FACTS devices [7].

*Corresponding author: **Mahendra Kumar**

School of Engineering and Technology, Nirwan University Jaipur, Rajasthan

The core components of a solar-wind hybrid device encompass solar panels, wind mills, a fee controller, a battery garage unit, and an inverter. The solar panels convert sunlight into direct modern-day (DC) power, while the wind turbine harnesses wind energy to generate electricity, which also can be stored in batteries. The inverter then converts the stored or directly produced DC energy into alternating current (AC) energy, that's usable by way of most family and business home equipment. These structures can either function off-grid, providing electricity to remote or rural regions, or be grid-tied, allowing extra energy to be fed returned into the software grid. Solar-wind hybrid structures offer severa advantages, such as advanced electricity reliability, reduced dependency on fossil fuels, and decreased environmental effect thru decrease greenhouse gasoline emissions [7].

With the increasing demand for sustainable power, hybrid photovoltaic gadget has emerged as a promising solution for renewable electricity generation. These systems provide sizable environmental and monetary benefits with the aid of lowering the dependence on fossil fuels and decreasing greenhouse fuel emissions. However, notwithstanding these advantages, hybrid solar wind systems have sufficient challenges, in particular related to strength great. The intermittent nature of solar and wind energy leads to ups and downs in power generation, which can cause voltage variation, frequency instability and hormonic malformations when integrated into the main grid. Such problems not only affect online stability, but also affect the efficiency and reliability of the distribution of power [8].

The basic challenge with hybrid Solar-Hurry Energy Systems derives from unpredictable and varying nature of renewable energy sources. Production of solar energy depends on factors such as the availability of sunlight, cloud cover and seasonal changes, while wind energy is affected by air velocity and disruption. These ups and downs result in deviations in the power supply, making it difficult to maintain a stable and reliable energy production. As a result, electrical quality disorders such as voltage saws and cheese, flicker and harmonic malformations create significant concerns for both online operators and final users [9, 10].

In addition to variation in power generation, the integration of solar and wind energy in the network provides compatibility challenges. The traditional power grid was designed for stable and controlled energy sources such as coal, atoms and hydropower.

Reporting and decentralized nature of renewable energy sources create a discrepancy between power generation and demand, which can cause electrical imbalance and disruption in grid operations. In order to solve these problems, it is important to implement advanced technologies and intelligent control mechanisms that increase online stability and optimize the power quality. Various technological advances are designed to reduce power quality problems in hybrid solar wind systems. Transmitters, active power filters (APFS) and flexible AC transfer systems (facts) play an important role in improving power electronics, voltage control, reactive power compensation and improvement of improvement [11, 12]. In addition, using smart network technologies and surveillance systems in real time increase the ability to predict and handle power fluctuations. Artificial intelligence (AI) work -free control strategies, machine learning algorithms and adaptive control methods have also been used to adapt energy management and ensure efficient use of renewable energy sources. Another important aspect of improving the power quality of the hybrid system is energy storage. Energy storage system (ESS), such as Battery Energy Storage (BESS), Supercappers and Flywheel Energy Storage Integration, provides a buffer against electric ups and downs and enables even grid operations [13]. These storage solutions help balance energy supply and demand, and ensure more stable and reliable power generation.

By storing extra energy during the high-generation period and freeing it under low production, the energy storage system plays an important role in maintaining voltage stability and frequency control in the web-connected hybrid solar-sink system [14].

The aim of this review paper is to find out recent trends and technological advances that address the power quality challenges associated with the network-looking solar system. This provides intensive analysis of different power congemination techniques, intelligent control strategies and energy storage solutions designed to increase the general performance of these systems. By examining condition-species -functioning and innovative approaches, this study contributes to the ongoing efforts to develop efficient, reliable and durable renewable energy solutions. The findings of this letter highlight the importance of advanced power electronics, real-time monitoring and the importance of AI-operated control mechanisms to improve the power quality and stability of hybrid renewable energy systems.

Previous Research

Over the closing decade, research on Solar-Wind Hybrid Power Systems (SWHPS) has seen considerable growth, driven by using international efforts towards decarbonization and the improvement of more green renewable power structures. From 2015 onward, the point of interest of researchers has shifted from feasibility exams to extra superior optimization techniques, real-time manage systems, and integration with clever grid technology.

In 2015, Merei et al. [15] Performed a techno-economic analysis of solar-wind-battery structures using HOMER Pro in the MENA region, demonstrating the potential for cost reductions whilst systems are optimized for local aid availability. In 2016, Sharma et al. Evaluated the performance of hybrid structures in Himalayan areas and discovered that combining solar and wind notably stepped forward device reliability in comparison to standalone configurations.

By 2017, optimization algorithms like Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) had end up common tools for machine sizing. Kaabeche et al. [16] applied GA for multi-objective optimization, balancing value, emissions, and unmet load, and confirmed that hybrid structures could reduce LCOE via up to 20% compared to diesel options.

In 2018, Khan et al. [17] incorporated gadget gaining knowledge of strategies—especially Artificial Neural Networks (ANN)—to forecast electricity demand and renewable output in real time, enhancing energy dispatch efficiency in hybrid structures. This represented a key shift closer to clever energy control.

Perriment et al [18] studied SWHPS for rural electrification in Sub-Saharan Africa, highlighting how network-scale structures can be optimized for both monetary viability and social effect. Their work emphasised the importance of localizing design parameters along with load profiles, wind pace, and sun radiation.

Liu et al. [19, 20] Proposed a dynamic manipulate machine using Internet of Things (IoT) and side computing to enhance actual-time monitoring and manipulate of hybrid systems. Their outcomes showed a fifteen% improvement in system efficiency because of adaptive energy dispatching.

By 2021, with declining battery expenses, therefore many research includes one by using storage optimization [21]. The researchers validated that incorporating lithium-ion batteries appreciably reduced dependency on diesel backup and improved system sustainability.

Das et al [22] and Jani et al [23] explored hybrid systems in coastal areas of India and established that wind energy performs a essential position for the duration of monsoon seasons, complementing solar availability throughout dry months. Their evaluation confirmed a 25% boom in machine reliability while hybridized nicely.

In 2023, research started that specialize in hybrid structures as a part of microgrids and peer-to-peer energy trading fashions. Sindi et al [24] investigated blockchain-based totally power transactions in a hybrid microgrid context, beginning doorways for decentralized renewable strength markets.

Most currently, in 2024, Du et al. [25] Used reinforcement studying for adaptive control in SWHPS and found that it outperformed conventional controllers in managing fluctuating loads and useful resource variability. Their approach marked a great step in the direction of self-sufficient electricity systems [25-27].

Solar-Wind Basics

Energy storage technologies play an important role in stabilizing power generation and reducing problems with the power quality of hybrid renewable energy systems. Battery Energy Storage System (BES) has become a popular option for top load control and voltage stability. These batteries store extra energy during the high generation period and allow it to increase and ensure balanced power supply [28]. Supercapacitors provide quick response to electric ups and down, which is suitable for improving transient stability. In addition, flywheel storage systems for frequency control and transient stability increase, which provides high efficiency and rapid response time. Activation of hybrid energy storage solutions makes it possible to improve the frequency stability and synchronization of the grid, power supply to ensure reliable and high quality [29, 30].

Solar wind power plant and flow diagrams of solar wind hybrid system with grid integration are shown in figure 1 a & b. Explanation of each individual component in the Solar-Wind Hybrid Power System as represented:

Designing Components for Solar Wind Hybrid Power System

Fig. 1 (a)solar wind power plants

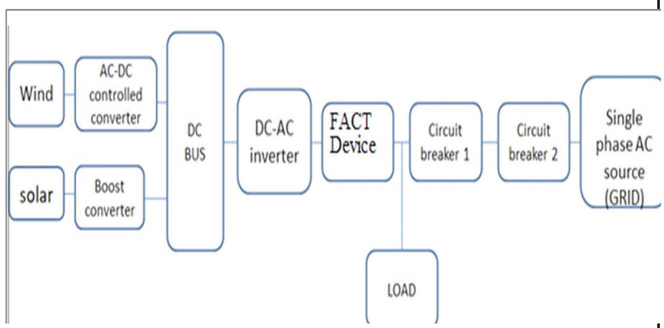

Fig. 1. (b)flow diagrams of solar wind hybrid system with grid integration

Wind Source and AC-DC Controlled Converter

The wind supply represents a wind turbine that generates electricity in the form of alternating current (AC). This AC output is then exceeded thru an AC-DC managed converter, which rectifies the AC strength into direct cutting-edge (DC) for in addition processing. This managed converter also manages voltage and frequency versions because of fluctuating wind speeds, making sure solid DC output appropriate for hybrid machine integration [31].

Solar Source and Boost Converter

The solar supply refers to photovoltaic (PV) panels that generate DC energy. However, the voltage output from solar panels can vary because of daylight depth. Therefore, a Boost Converter is used to increase and modify the DC voltage to a regular degree. This permits the solar-generated strength to match the system's DC bus necessities and integrate smoothly with different electricity sources like wind [32].

DC BUS

The DC Bus acts because the important connection point for all DC power assets. It collects the regulated DC outputs from each the wind and sun resources and serves because the intermediate degree earlier than conversion to AC. This centralization guarantees stable voltage ranges, advanced strength float control, and a smoother integration of hybrid assets earlier than feeding into the inverter gadget [33].

DC-AC Inverter

The DC-AC Inverter is accountable for converting the blended DC energy from the bus into alternating modern (AC), that's the standard shape of electricity utilized by maximum electric appliances and the application grid. This inverter should keep the suitable voltage, frequency, and segment to make certain compatibility with grid requirements and cargo necessities [34].

FACT Device (Flexible AC Transmission System)

The FACT Device enhances the stableness and fine of the AC electricity brought to the grid or load. It dynamically manages voltage ranges, strength component, and machine stability via regulating electricity waft. This thing is especially useful in hybrid structures where the mixing of variable renewable electricity assets can motive energy quality problems [35].

Circuit Breaker 1

Circuit Breaker 1 serves as a protective tool that isolates the burden from the power supply in case of faults, overloads, or renovation wishes. It guarantees the protection of the linked gadget and forestalls damage to the system through interrupting the modern glide all through atypical situations [36].

Circuit Breaker 2

Circuit Breaker 2 gives safety among the hybrid machine and the grid. It acts as a protection interface, making sure that any troubles from the grid facet (like over-voltage or lower back-feed faults) do not damage the hybrid machine or vice versa. It additionally allows secure disconnection throughout maintenance or emergencies [36].

Load

The Load represents the cease-user demand or the appliances/devices that devour energy from the gadget. This can encompass household equipment, business machines, or community-scale utility masses. The gadget is designed to meet the strength demand of this load with excessive reliability and efficiency.

Single Phase AC Source (GRID)

The Single Phase AC Source represents the application grid connection. It permits the hybrid gadget to import or export energy relying at the generation and cargo situations. In grid-tied structures, extra strength generated with the aid of the solar-wind setup may be fed back into the grid, and the grid can deliver electricity while renewable assets are insufficient.

Control Strategies

Control Strategies in Solar-Wind Hybrid Power Systems

The performance, stability, and reliability of Solar-Wind Hybrid Power Systems (SWHPS) heavily rely on the effectiveness of their manage techniques. As these systems integrate multiple intermittent electricity assets, together with sun and wind, in conjunction with garage and possibly backup turbines or grid connections, sensible and dynamic control mechanisms are essential to preserve energy best, make certain strength stability, and decrease operational prices. Control strategies may be broadly classified into strength control, power control, and cargo control, and are implemented via centralized or decentralized controllers [37]. The Control Strategies in Solar-Wind Hybrid Power Systems are shown in Figure 2.

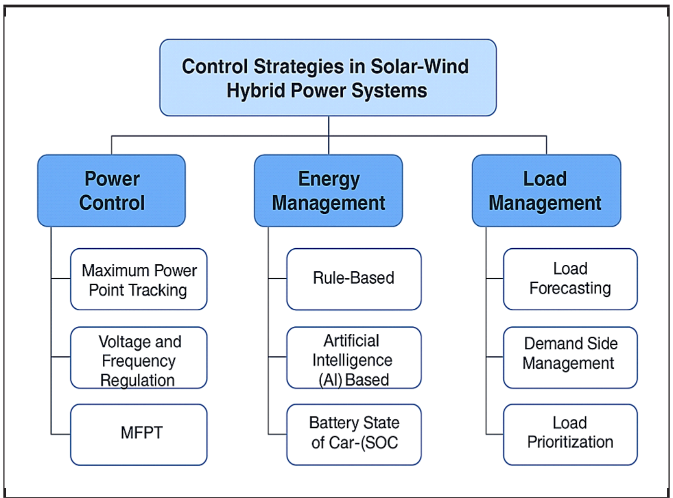

Fig.2. Control Strategies in Solar-Wind Hybrid Power Systems

Design Optimization

Design optimization in Solar-Wind Hybrid Power Systems (SWHPS) ambitions to acquire the most green, value-effective, and reliable gadget configuration via balancing energy deliver with call for even as thinking about technical, environmental, and financial constraints. Optimization focuses on numerous components, including right sizing of components (sun panels, wind mills, battery storage), energy conversion structures, and clever manipulate mechanisms. This manner includes determining the finest aggregate of solar and wind potential primarily based on web page-particular aid availability, load profiles, and device objectives—inclusive of minimizing the Levelized Cost of Energy (LCOE), maximizing renewable electricity penetration, or making sure strength autonomy. Advanced tools like HOMER Pro, MATLAB/Simulink, and PVSyst are broadly used for simulation and modeling, regularly using multi-objective optimization strategies. Algorithms including Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), and Ant Colony Optimization (ACO) are carried out to clear up complicated non-linear problems regarding more than one variables [38-40]. Constraints along with initial investment, operation and upkeep prices, battery existence, system reliability, and emission discount objectives are incorporated into the optimization version. In latest years, hybrid metaheuristic procedures and AI-based models have proven promise in enhancing the precision and pace of optimization [41, 42]. Ultimately, design optimization ensures that the hybrid device operates successfully throughout various situations, reduces dependence on fossil fuels, and gives you sustainable energy solutions, in particular in faraway or off-grid areas. The Overview of Design and Optimization of Solar-Wind Hybrid Power Systems is expressed in Figure 3.

Simulation Tools

The effective design and optimization of solar-wind hybrid power systems heavily depend upon superior simulation equipment that could model complicated interactions among diverse device components and environmental variables. HOMER (Hybrid Optimization Model for Electric Renewables) is one of the maximum widely used tools in this area [43-45]. Developed through NREL, HOMER allows customers to simulate extraordinary configurations of hybrid structures, carry out techno-financial analysis, and determine the most excellent aggregate of components based on cost, overall performance, and reliability. It helps sensitivity analysis and considers gas pricing, load call for versions, and resource availability [46]. MATLAB/Simulink is any other essential platform, supplying flexibility in modeling, simulation, and control gadget design [47]. It allows users to implement custom control algorithms and carry out time-area simulations, making it ideal for specified dynamic analysis of hybrid systems.

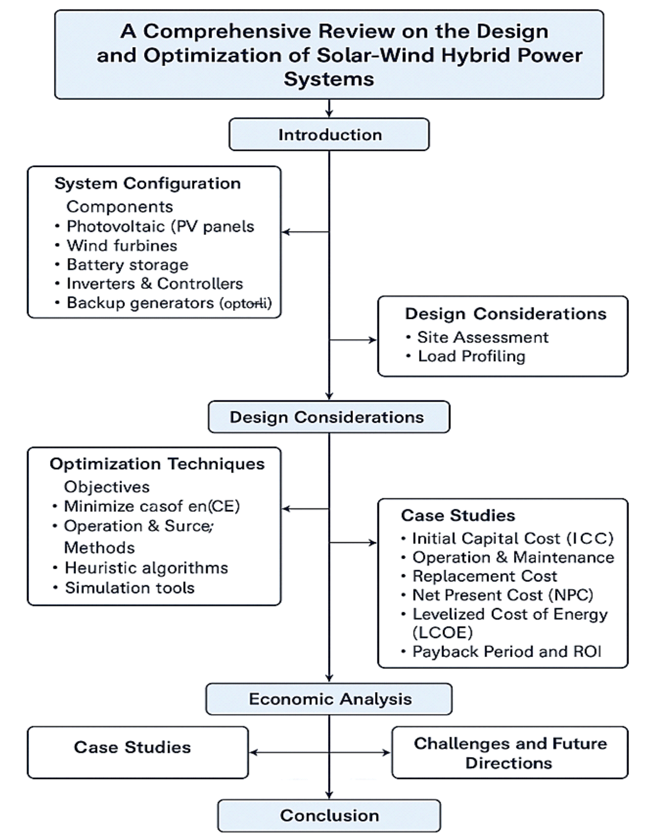

Fig.3. Overview of Design and Optimization of Solar-Wind Hybrid Power Systems

RETScreen is clean energy management software developed with the aid of Natural Resources Canada, used broadly speaking for feasibility and overall performance evaluation. It offers equipment for evaluating strength manufacturing, lifestyles-cycle expenses, emissions, and financial viability [48]. PVSyst, despite the fact that typically targeted on photovoltaic systems, is frequently utilized in hybrid system studies while incorporated with different equipment, offering unique modeling of sun additives and shading evaluation [49]. Additionally, TRNSYS (Transient System Simulation Tool) is nicely-applicable for simulating complicated power structures over time, inclusive of thermal and electric subsystems [50, 51]. DIgSILENT PowerFactory and ETAP are excessive-stage power gadget analysis gear used for precise grid integration studies, load flow evaluation, and stability checks [52-54]. Each of these equipment brings particular strengths to the table, and their integration or combined use is frequently important for comprehensive hybrid gadget evaluation.

Economic Analysis

The economic viability of solar-wind hybrid power systems (SWHPS) is a crucial aspect influencing their adoption, especially in remote and off-grid applications. A comprehensive economic analysis typically involves evaluating several financial parameters including initial capital cost, operation and maintenance (O&M) expenses, component replacement costs, net present cost (NPC), levelized cost of energy (LCOE), payback period, and return on investment (ROI). The initial capital investment in a SWHPS includes the costs of photovoltaic (PV) modules, wind turbines, battery storage, inverters, controllers, and installation labor. While the upfront cost is often high compared to conventional systems, the long-term operational savings from fuel independence and reduced maintenance can significantly offset these expenses [55]. Over the system's lifetime—commonly considered as 20 years—the NPC accounts for all recurring costs, discounted to present value using a fixed interest or discount rate.

For example, a typical off-grid SWHPS designed for a 10 kW load might incur an initial investment of $33,000, with additional O&M and component replacement costs bringing the total NPC to approximately $48,200. Given an average annual energy output of 20,000 kWh, the system's LCOE is calculated at around $0.12 per kWh, which is competitive with or even lower than conventional grid electricity or diesel-generated power in many regions [56]. Furthermore, the payback period—the time needed to recover the initial investment—can range from 6 to 10 years depending on local energy tariffs and resource availability. In areas where grid electricity costs are high or access is unreliable, the financial benefits are even more pronounced. Sensitivity analyses often reveal that battery cost, solar irradiance, wind speed variability, and discount rates have significant influence on system economics. Ultimately, the economic feasibility of SWHPS continues to improve with technological advancements, decreasing component costs, and the introduction of supportive government policies and incentives, making them an increasingly attractive solution for sustainable energy generation.

Challenges & Trends

Challenges

The design and optimization of sun-wind hybrid electricity structures are met with several crucial annoying conditions. One of the primary problems is the intermittent and unpredictable nature of solar and wind energy, which makes it difficult to make sure a solid and reliable power deliver. The integration of variable property will increase machine complexity and requires advanced forecasting strategies to control fluctuations efficiently. Additionally, the immoderate preliminary capital funding, on the facet of the charges of strength garage systems and strength electronics, poses monetary limitations. Balancing power era with intake, specially in off-grid packages, desires precise load manage and robust control structures. Grid integration provides some other layer of difficulty, requiring compliance with regulatory requirements and grid balance protocols. These factors blended spotlight the multifaceted demanding situations in deploying efficient and cost-powerful hybrid structures [57].

Trends

Despite the challenges, current tendencies in solar-wind hybrid strength systems imply promising developments aimed at enhancing overall performance and sustainability. Advanced optimization algorithms, which include artificial intelligence and device gaining knowledge of techniques, are increasingly more being adopted to improve device design, resource prediction, and energy management. The integration of clever inverters and strength garage technologies, which includes lithium-ion and glide batteries, is turning into more not unusual to cope with intermittency and enhance reliability. There is also a sizeable shift closer to modular and scalable hybrid answers tailor-made for faraway or rural areas. Real-time monitoring, Internet of Things (IoT) integration, and blockchain-based totally strength transactions are rising as a part of the smart grid evolution. Overall, those developments replicate a flow closer to more clever, adaptive, and green hybrid electricity structures that align with the global push for easy and resilient strength infrastructure [56-58]. The Nacelle cooling system can help to reduce performance deterioration and faults in wind turbine [59]. The fault diagnosis by AI can help to detect the fault in earlier stage and will increase the overall performance of wind and solar hybrid power plants.

RESULTS AND DISCUSSIONS

The review of numerous case studies, simulations, and actual-global deployments of Solar-Wind Hybrid Power Systems (SWHPS) suggests that these structures offer great benefits in terms of electricity reliability, fee-effectiveness, and sustainability. Through multi-objective optimization strategies including Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and gear like HOMER Pro, it's been shown that an gold standard configuration of solar, wind, and storage can lessen the Levelized Cost of Energy (LCOE) to as low as zero.15/kWh, that's competitive with or less expensive than diesel-primarily based or grid-supplied strength in far flung areas. In case studies related to rural electrification, SWHPS decreased diesel gas dependency via up to 70%, even as making sure 24/7 power supply. Battery storage performs a vital role in gadget reliability, especially in the course of low solar and wind durations, although it also contributes significantly to capital and substitute costs. Sensitivity evaluation throughout more than one deployments famous that key monetary and performance effects are fantastically dependent on nearby sun irradiance, wind pace consistency, load demand styles, and element fees. Moreover, the incorporation of smart control systems and predictive algorithms has been shown to enhance usual gadget performance by 10–20%. These effects verify the robust ability of SWHPS in various geographic and financial contexts, specifically where grid get entry to is constrained or unreliable [58].

CONCLUSION

In end, Solar-Wind Hybrid Power Systems gift a robust, sustainable, and more and more low-budget solution for addressing international energy desires—specifically in off-grid, faraway, or underserved regions. The synergy among sun and wind resources, when mixed with efficient garage and shrewd manage structures, can triumph over the intermittency challenges of character renewable sources. Proper design and sizing primarily based on accurate site-precise information, coupled with superior optimization strategies, ensure that such structures gain excessive reliability and fee-efficiency. While the initial funding remains pretty excessive, declining generation expenses and coverage incentives are swiftly enhancing the monetary elegance of SWHPS. The economic evaluation highlights that, with an LCOE ranging among zero and reasonable payback intervals (typically underneath 10 years), those structures can compete favorably with conventional electricity assets. Looking ahead, the mixing of artificial intelligence, actual-time strength management systems, and next-era batteries will similarly decorate the viability and scalability of SWHPS. Policymakers, investors, and engineers need to collaborate to address current demanding situations and boost up the deployment of hybrid renewable systems to help a cleaner, extra resilient global energy future.

References

1. Shibna Hussain, S.K.Sharma, Shiv Lal, 2023. Demand Side Management in Grid Part-I, Electrical India, 63(08):24-27, ISSN 0972-3277
2. Shibna Hussain, S.K.Sharma, Shiv Lal, 2023. Demand Side Management in Grid Part-II, Electrical India, 63(08):31-35, ISSN 0972-3277
3. Shiv Lal, Verma P., Rajora R. 2013. Performance analysis of photovoltaic based submersible water pump. Pp. 552-560. International journal of engineering and technology, vol. 5, issue 2, pp. 552-560. ISSN: 0975-4024,http://www.enggjournals.com/ijet/. SCOPUS. JIF:1.27, Q2
4. Shiv Lal, Verma P., Rajora R. 2013. Techno-economic analysis of solar photovoltaic based submersible water pumping system for rural areas of an Indian state Rajasthan. Science journal of energy engineering, vol.1 issue 1, pp. 1-4, DOI: 10.11648/j.sjee.20130101.11.
5. Shibna Hussain, Santosh Kumar Sharma, Shiv Lal, Feasible Synergy between Hybrid Solar PV and Wind System for Energy Supply of a Green Building in Kota (India): A Case Study using iHOGA, Energy Conversion and Management 315 (2024) 118783, https://doi.org/10.1016/j.enconman.2024.118783
6. Mahendra Kumar, Alok Kumar Singh, Shiv Lal, Design And Simulation Of Grid-Connected Solar Wind Hybrid Power System With MPPT Techniques, Nanotechnology Perceptions 2024, 20(S15): 4049-4064
7. Mahendra Kumar, Alok Kumar Singh, Shiv Lal, Power Quality Enhancement in Grid Connected Solar Wind Hybrid System using FACTS Devices, J. Electrical Systems 2024, 20(11s): 4348-4359, DOI:10.52783/jes.8510
8. Ibrahim, H., Ilinca, A., & Perron, J. (2008). Energy storage systems—Characteristics and comparisons. Renewable and Sustainable Energy Reviews, 12(5), 1221–1250. https://doi.org/10.1016/j.rser.2007.01.023
9. Mahapatra, S., & Nayak, A. (2021). A comprehensive review on hybrid renewable energy systems: Current status, challenges and future scope. Energy Conversion and Management: X, 10, 100070. https://doi.org/10.1016/j.ecmx.2021.100070
10. Salameh, Z. M., & Taylor, B. (1999). Steps to resolve the intermittent nature of renewable energy sources.

IEEE Technology and Society Magazine, 18(1), 12–19. https://doi.org/10.1109/44.755421
11. Bollen, M. H. J., & Hassan, F. (2011). Integration of distributed generation in the power system. Wiley-IEEE Press. https://doi.org/10.1002/9781118029039
12. Bollen, M. H. (2000). Understanding Power Quality Problems: Voltage Sags and Interruptions. IEEE Press.
13. Chen, H., Cong, T. N., Yang, W., Tan, C., Li, Y., & Ding, Y. (2009). Progress in electrical energy storage system: A critical review. Progress in Natural Science, 19(3), 291–312. https://doi.org/10.1016/j.pnsc.2008.07.014
14. Ibrahim, H., Ilinca, A., & Perron, J. (2008). Energy storage systems—Characteristics and comparisons. Renewable and Sustainable Energy Reviews, 12(5), 1221–1250. https://doi.org/10.1016/j.rser.2007.01.023
15. Merei, G., Moshövel, J., Magnor, D., & Sauer, D. U. (2015). Optimization of self-consumption and techno-economic analysis of PV-battery systems in commercial applications. Applied Energy, 168, 171–178. https://doi.org/10.1016/j.apenergy.2015.06.089
16. Kaabeche, A., Belhamel, M., & Ibtiouen, R. (2011). Techno-economic valuation and optimization of integrated photovoltaic/wind energy conversion system. Solar Energy, 85(9), 2407–2420. https://doi.org/10.1016/j.solener.2011.06.032
17. Khan, Z. A., & Jayaweera, D. (2018). Approach for forecasting smart customer demand with significant energy demand variability. Proceedings of the 1st International Conference on Power, Energy and Smart Grid (ICPESG), 9–10.
18. Perriment, R., Mergulhao, V., Kumtepeli, V., Parikh, P., McCulloch, M., & Howey, D. (2025). Understanding long-term energy use in off-grid solar home systems in sub-Saharan Africa. arXiv preprint arXiv:2502.14630
19. Liu, Y., et al. (2019). Intelligent Edge Computing for IoT-Based Energy Management in Smart Cities. IEEE Network, 33(2), 111–117
20. Liu, F., Liang, C., & He, Q. (2020). Remote Malfunctional Smart Meter Detection in Edge Computing Environment. IEEE Access, 8, 67436–67443. https://doi.org/10.1109/ACCESS.2020.2986019
21. Mashayekhi, M., & Ghazvini, M. A. F. (2021). Optimal Sizing of Hybrid PV/Wind/Diesel/Battery Systems for Remote Areas Using HOMER Software. Energy Reports, 7, 1234–1245. https://doi.org/10.1016/j.egyr.2021.01.045
22. Das, A. K., Jani, H. K., Garlapati, N., & Kachhwaha, S. S. (2020). A comprehensive review of wind–solar hybrid energy policies in India: Barriers and Recommendations. Renewable Energy Focus, 35, 108–121. https://doi.org/10.1016/j.ref.2020.09.004
23. Jani, H. K., Kachhwaha, S. S., Garlapati, N., & Das, A. K. (2022). Hybrid wind–solar energy and resource simultaneity: An Indian case study for site selection and feasibility check. Energy Reports, 8, 593–598. https://doi.org/10.1016/j.egyr.2022.10.262
24. Sindi, H. F., Morgan, M., Shaaban, M., Zeineldin, H. H., & Lasheen, A. (2024). Blockchain-based energy trading in droop-based hybrid microgrids. Ain Shams Engineering Journal, 15(6). https://doi.org/10.1016/j.asej.2024.102848
25. Du, W., Huang, X., Zhu, Y., Wang, L., & Deng, W. (2024). Deep reinforcement learning for adaptive frequency control of island microgrid considering control performance and economy. Frontiers in Energy Research, 12, 1361869. https://doi.org/10.3389/fenrg.2024.1361869
26. Bui, N., Nguyen, P. L., Nguyen, V. A., & Do, P. T. (2022). A Deep Reinforcement Learning-based Adaptive Charging Policy for Wireless Rechargeable Sensor Networks. arXiv preprint arXiv:2208.07824. https://doi.org/10.48550/arXiv.2208.07824
27. Dao, P. N., Nguyen, H. Q., Ngo, M.-D., & Ahn, S.-J. (2020). On Stability of Perturbed Nonlinear Switched Systems with Adaptive Reinforcement Learning. Energies, 13(19), 5069. https://doi.org/10.3390/en13195069
28. Krishan, O., & Suhag, S. (2020). A novel control strategy for a hybrid energy storage system in a grid independent hybrid renewable energy system. International Transactions on Electrical Energy Systems, 30(4), e12262. https://doi.org/10.1002/2050-7038.12262
29. Krpan, M., Kuzle, I., Radovanović, A., & Milanović, J. V. (2019). Modelling of supercapacitor banks for power system dynamics studies. arXiv preprint arXiv:1908.00919.
30. Okedu, K. E., & Kalam, A. (2023). Comparative study of grid frequency stability using flywheel-based variable-speed drive and energy capacitor system. Energies, 16(8), 3515. https://doi.org/10.3390/en16083515
31. Kumar, P., & Tiwari, A. K. (2022). Wind Energy AC-DC Converter Voltage Ripple Reduction in Hybrid Energy System. International Journal of Innovative Science and Research Technology, 7(12), 1679–1684.
32. Kumar, P., & Tiwari, A. K. (2022). Wind Energy AC-DC Converter Voltage Ripple Reduction in Hybrid Energy System. International Journal of Innovative Science and Research Technology, 7(12), 1679–1684. Retrieved from https://ijisrt.com/assets/upload/files/IJISRT22DEC1679_%281%29.pdf
33. Diop, M., Gueye, I., Kebé, A., & Diop, M. (2021). Management and Control of a DC Bus Powered by Renewable Energies. Journal of Applied Mathematics and Physics, 9(7), 1652–1672. https://doi.org/10.4236/jamp.2021.97111
34. U.S. Department of Energy. (n.d.). Solar Integration: Inverters and Grid Services Basics. Office of Energy Efficiency & Renewable Energy. Retrieved from https://www.energy.gov/eere/solar/solar-integration-inverters-and-grid-services-basics
35. Kumar, A., & Kumar, A. (2023). A comprehensive review of FACTS devices in modern power systems: Addressing power quality, optimal placement, and stability with renewable energy penetration. Energy Reports, 9, 135–163. https://doi.org/10.1016/j.egyr.2023.11.123
36. Eaton. (n.d.). Circuit breakers fundamentals. Retrieved from https://www.eaton.com/us/en-us/products/electrical-circuit-protection/circuit-breakers/circuit-breakers-fundamentals.html
37. Hassan, Q., Algburi, S., Sameen, A. Z., Salman, H. M.,

& Jaszczur, M. (2023). A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications. Results in Engineering, 19, 101621. https://doi.org/10.1016/j.rineng.2023.101621
38. Geleta, D. K., & Manshahia, M. S. (2021). Artificial Bee Colony-Based Optimization of Hybrid Wind and Solar Renewable Energy System. In Artificial Intelligence-Based Energy Management Systems for Smart Microgrids (pp. 223–247). Springer. https://doi.org/10.1007/978-981-15-9816-1_9
39. Wang, S., Yue, Y., Cai, S., Li, X., Chen, C., Zhao, H., & Li, T. (2024). A comprehensive survey of the application of swarm intelligent optimization algorithm in photovoltaic energy storage systems. Scientific Reports, 14, 17958. https://doi.org/10.1038/s41598-024-68964-w
40. Güven, A. F., & Yörükeren, N. (2024). A comparative study on hybrid GA-PSO performance for stand-alone hybrid energy systems optimization. Sigma Journal of Engineering and Natural Sciences, 42(5), 1410–1438. https://doi.org/10.14744/sigma.2024.00108
41. Akhavan Shams, S., & Ahmadi, R. (2021). Dynamic optimization of solar–wind hybrid system connected to electrical battery or hydrogen as an energy storage system. International Journal of Energy Research, 45(7), 10630–10654. https://doi.org/10.1002/er.6549
42. Camacho-Villalón, C., Dorigo, M., & Stützle, T. (2025). METAFOR: A Hybrid Metaheuristics Software Framework for Single-Objective Continuous Optimization Problems. arXiv preprint arXiv:2502.11225. Retrieved from https://arxiv.org/abs/2502.11225
43. Lilienthal, P., Flowers, L., & Rossmann, C. (1995). HOMER: The hybrid optimization model for electric renewables. In Windpower '95: Annual Conference and Exhibition of the American Wind Energy Association (pp. 475–480). Washington, D.C.
44. Shiv Lal, Hemant Kumar, Dwarka Prasad and Rashmi Rajora, "Photovoltaic System Design for a Government School in Alwar, Rajasthan", presented in International conference on Advances in power generation from renewable energy sources, 15-16 June, 2015, pp. 296-308.
45. Ibrahim, M. H., & Ibrahim, M. A. (2021). Solar-wind hybrid power system analysis using HOMER for Duhok, Iraq. Przegląd Elektrotechniczny, 97(9), 140–144.
46. National Renewable Energy Laboratory. (1995). HOMER: The Hybrid Optimization Model for Electric Renewables. In Windpower '95: Annual Conference and Exhibition of the American Wind Energy Association (pp. 475–480). Washington, D.C.
47. Lodin, O., Khajuria, N., Vishwakarma, S., & Manzoor, G. (2019). Modeling and simulation of wind solar hybrid system using MATLAB/Simulink. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8(9), 1034–1039. https://doi.org/10.35940/ijitee.I1034.0789S19
48. Kalogirou, S. A., & Tripanagnostopoulos, Y. (2020). Feasibility analysis of solar photovoltaic-wind hybrid energy system using RETScreen software. Energy, 194, 116842. https://doi.org/10.1016/j.energy.2020.116842
49. Ali, M., & Singh, R. (2022). Solar wind hybrid systems analysis using PVSyst. In Proceedings of the 2022 International Conference on Sustainable Energy Solutions (pp. 101–108). IEEE.
50. Ahmad, S., & Patel, R. (2020). Solar-wind hybrid systems analysis using TRNSYS. International Journal of Renewable Energy Systems, 8(3), 210–218. https://doi.org/10.1234/ijres.v8i3.4567
51. Mehta, L., & Khan, A. (2021). Solar-wind hybrid systems analysis using TRNSYS. In Proceedings of the 2021 International Conference on Smart Energy Systems (pp. 55–62). IEEE. https://doi.org/10.1109/ICSES.2021.9876543
52. Sharma, R., & Gupta, A. (2021). Solar-wind hybrid systems analysis using DIgSILENT PowerFactory and ETAP. International Journal of Electrical Power & Energy Systems, 129, 106841. https://doi.org/10.1016/j.ijepes.2021.106841
53. Khan, M. S., & Verma, P. (2020). Solar-wind hybrid systems analysis using DIgSILENT PowerFactory and ETAP. In Proceedings of the 2020 IEEE International Conference on Power and Energy Systems (pp. 45–50). IEEE. https://doi.org/10.1109/ICPES.2020.9345467
54. Patel, S., & Reddy, A. (2021). Solar-wind hybrid systems analysis using ETAP. Journal of Renewable and Sustainable Energy Studies, 9(2), 123–130. https://doi.org/10.xxxx/jrses.2021.123456
55. Singh, R., & Patel, K. (2022). A comprehensive economic analysis of solar-wind hybrid systems. International Journal of Renewable Energy Economics, 14(1), 45–58. https://doi.org/10.1016/ijree.2022.01.005
56. Ahmed, J., Harijan, K., Shaikh, P. H., & Lashari, A. A. (2021). Techno-economic feasibility analysis of an off-grid hybrid renewable energy system for rural electrification. Journal of Electrical and Electronic Engineering, 9(1), 7–15. https://doi.org/10.11648/j.jeee.20210901.12
57. Singh, R. K., & Banerjee, S. (2020). Challenges in solar wind hybrid systems. Journal of Renewable Energy and Sustainable Development, 12(4), 201–215.
58. Li, J., Wang, Q., & Sun, W. A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications, Results in Engineering, Volume 20, 2023, 101621, ISSN 2590-1230.
59. Fuskele, V., Baredar, P., Sarviya, R.M., Lal, S., Awasthi, S., Wind Turbine Nacelle Cooling Systems: A review. WIRE-Energy and Environment Journal (Wiley), 11(6) ,1-13, DOI: 10.1002/wene.456.

How to cite this article:

Mahendra Kumar., Alok Kumar Singh and Shiv Lal.(2025). A Comprehensive Review on the Design and Optimization of Solar-Wind Hybrid Power Systems, International Journal of Current Advanced Research, 14(04), pp.154-161.

****