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Research Article

Performance And Optimization Of Solar Photovoltaic-Wind Hybrid Energy Systems

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ABSTRACT

Solar photovoltaic-wind hybrid energy systems have been developed in response to the growing global demand for sustainable energy. They provide a dependable and effective substitute for conventional power generation. Through the integration of solar PV panels, wind turbines, energy storage, and energy management systems, this study investigates the performance and optimization of such hybrid systems. The project aims to increase energy output, enhance efficiency, and minimize costs using cutting-edge optimization approaches like Genetic Algorithms (GA) and Particle Swarm Optimization (PSO). The findings show that hybrid systems perform better in terms of energy generation and cost-effectiveness than standalone solar or wind systems when they are appropriately tuned. Solar PV-wind hybrid systems are a viable option for sustainable energy development since they lessen dependency on fossil fuels and increase system reliability, especially in regions with diverse environmental circumstances.

Keywords: Solar Photovoltaic-Wind, Hybrid Energy,Optimization, Environmental Circumstances, Genetic Algorithms (Ga), Particle Swarm Optimization (PSO).

1. INTRODUCTION

A major increase in the world's energy demand has been observed in recent years, primarily due to technological improvements, industrial expansion, and population growth. Interest in renewable energy systems has grown in reaction to the environmental problems that traditional fossil fuel-based energy sources bring. Among these, hybrid energy systems—that is, systems that combine wind and solar photovoltaic (PV)—have shown promise as reliable and sustainable energy sources. In addition to providing the benefit of combining two plentiful and complementary renewable energy sources, hybridizing solar and wind energy systems also improves overall power supply stability and efficiency, particularly in off-grid or remote areas.
Solar photovoltaic (PV) systems use semiconductor materials to capture solar radiation energy and transform it into electrical power. Because of its scalability, simplicity of installation, and decentralized electricity generation capabilities, photovoltaic systems have become more and more popular. However, solar irradiance, which varies with the time of day, the weather, and seasonal variations, has a significant impact on their effectiveness. However, wind energy systems provide an additional power source, particularly in times of low solar activity, by converting wind energy from kinetic energy to electrical power. A solar PV system that incorporates wind power can reduce the intermittency problems that come with using each energy source separately, resulting in a more steady and dependable power supply.
For solar PV-wind hybrid energy systems to reach their full potential and maintain economic sustainability, performance and optimization are essential. PV panels, wind turbines, inverters, and energy storage systems are examples of system components that must be carefully chosen and sized in order to get optimal results. In order to ensure that the energy generated efficiently fulfills the demand while reducing losses and guaranteeing cost-effectiveness, these components must be engineered to work in unison. Real-time monitoring systems and sophisticated control algorithms are required for the hybrid system to be able to adapt to changing load requirements and weather conditions.
Ensuring that solar PV-wind hybrid systems function well in a variety of environmental circumstances is a significant design and optimization problem. Temperature fluctuations, wind speed, and solar irradiation all

have a big impact on how much energy these systems produce. As a result, system designers need to take into consideration local climate trends, maximize PV panel tilt angle and orientation, and use wind turbines that are appropriate for the area's wind profile. Moreover, integrating energy storage devices—like batteries—is crucial to maintaining supply and demand equilibrium, especially when renewable energy production is at a low.

There are a lot of chances to reduce carbon emissions and advance sustainable development when solar and wind energy are combined. It is possible to lessen reliance on non-renewable energy sources, cut greenhouse gas emissions, and boost international efforts to mitigate climate change by improving the performance of these systems. In addition, hybrid energy systems present a workable way to lower energy poverty, electrify rural locations, and give places not connected to the central grid a reliable power source.

1.1 Global Energy Demand and Sustainability Challenges

The old energy networks are under tremendous strain because to the sharp rise in global energy demand, which is being caused by urbanization, population growth, and industrial expansion. The world's energy supply is still dominated by conventional fossil fuels like coal, oil, and natural gas, which greatly increase greenhouse gas emissions and degrade the environment. Air pollution, climate change, and resource depletion are just a few of the environmental issues brought on by this reliance on non-renewable energy sources. Sustainable and renewable energy sources that can lower carbon emissions and lessen the negative environmental effects of energy production are desperately needed to address these problems. In addition to being more sustainable and clean, renewable energy sources like wind and solar have the capacity to supply the world's expanding energy needs with the least amount of negative environmental impact and by lowering reliance on limited resources.

1.2 Hybrid Energy Systems: Concept and Benefits

The drawbacks of isolated renewable energy sources can be creatively addressed with hybrid energy systems, which integrate solar photovoltaic (PV) and wind power. These systems produce a more balanced and consistent energy output by taking advantage of the complementing qualities of solar and wind resources, which are stronger at night and during overcast times and abundant during the day, respectively. By combining the two energy sources, the intermittency problems that arise from using just one of them are lessened, improving efficiency and providing a constant power source. Because of this, hybrid systems are more stable and dependable, which makes them a wonderful option for satisfying energy needs in a way that is both economical and sustainable.

2. REVIEW OF LITREATURE

Abaye, A. E. et.al. (2018) One significant energy source that satisfies the need for power is environmentally friendly power. The use of elective energy sources, either in independent or framework coordinated structure, is exhibited by ebb and flow research commitments and news reports from everyday encounters. To further develop exactness and decrease calculation time, scientists utilized both old and new age man-made brainpower algorithms. PV-Wind hybrid framework examination and optimization have been finished with man-made consciousness frameworks. This work tries to go over a calculated examination of battery stockpiling and PV-wind energy framework demonstrating. Analysts will track down this audit accommodating in handling the complexity of algorithms for improved examination and plan of force framework.

Acuña, L. G. et.al (2018) Since there is a need to utilize reasonable, environmentally valuable, and locally accessible energy sources, hybrid photovoltaic-wind energy frameworks are being arranged and executed as independent or network associated age frameworks. This work presents a clever way for improving the size of an independent hybrid photovoltaic-wind power framework that incorporates battery capacity. The all out net current expense and a clever unwavering quality marker called greatest anticipated energy not provided — which is resolved utilizing a probabilistic method — as well as a multi-objective optimization issue are inspected. The model arrangement was tracked down utilizing the non-ruled arranging genetic calculation II. The proposed philosophy created a bunch of serviceable arrangements, with regard to framework economy and unwavering quality, that expands the utilization of sustainable sources and limits the size of the framework reinforcement. The outcomes got with the introduced technique were contrasted and those from customary systems.

Anoune, K., Ghazi et.al (2020) To tackle the measuring optimization challenge, a heuristic procedure in light of a genetic calculation is made and composed into MATLAB. Two essentials were accommodated the objective capability: the levelized cost of energy (LCE) and the likelihood of the deficiency of force supply (LPSP). To decide the legitimate part size of a PV-Wind based hybrid framework (PWHS), measuring optimization arrangements are created and analyzed utilizing a period series energy trade during a delegate week in each season.

Bansal, A. K. et.al (2022) India's advancement in the domain of sustainable sources can empower it to stay up with worldwide headways in both financial and social spaces. In far off regions where network access is unfeasible or restrictively costly, hybrid energy frameworks are encouraged to meet the electric power prerequisites of one or numerous clients for private or horticultural purposes. Solar cells, wind turbine generators, hydro power plants, and diesel motor generators can all deliver power in places without matrix network. For far off areas, producing the necessary electrical energy by consolidating many sources is conceivable. A hybrid energy framework is made when most of the sources are environmentally friendly power sources.

Bukar, A. L. et.al (2019) This paper surveys energy the executives methodologies (EMS) and framework optimization for a power module coordinated independent photovoltaic and wind energy framework. Tracking down the right blend of situation parts to make a framework that is financially savvy is the point of optimization. The objective of the EMS is to adjust load interest and different impediments while planning the power stream of the framework's constituent parts. It is remarkable to address framework optimization and EMS independently from the point of view of framework level plan as a result of their blend. Consequently, the overall definition structure for optimization as well as the order and survey of various types of optimization strategies are expounded in this review. The writing on EMS examination and application is additionally inspected.

3. METHODOLOGY

3.1 System Design and Architecture

In order to control the load and combine power output from both sources, the hybrid system used in this study consists of solar PV panels, wind turbines, energy storage (battery banks), and an energy management system (EMS). Because solar and wind resources are erratic, the system architecture is built to compensate for this and ensure continuous power output.

MATLAB/Simulink and HOMER Pro software are used to model the hybrid system in order to simulate various configurations and maximize their performance. Variations in weather, location, and energy use are taken into consideration in the simulation.

3.2 Data Collection

The following data were utilised in this study:

Data on solar irradiance: To evaluate the availability of solar energy, historical data on solar irradiance is gathered from a nearby weather station.

Wind speed data: Measurements of wind speed taken in the same area are essential for calculating the amount of energy generated by wind turbines.

Energy demand profile: A local community's hourly and daily load requirements, used to assess system dependability.

Cost information: The costs associated with equipment and operations, such as maintenance, capital expenditures (CapEx), and operating expenditures (OpEx).

3.3 Performance Metrics

The following key performance indicators (KPIs) are used to assess the effectiveness of the system:

Energy Output (kWh): The total energy produced by the hybrid system, taking into account the contributions of wind turbines and photovoltaic panels.

Efficiency (%): The energy conversion efficiency of the system, taking into consideration power conversion and storage losses.

Reliability (%) is defined as the capacity to continuously supply energy while accounting for disruptions brought on by resource unpredictability.

Cost-Effectiveness ($/kWh): The energy system's lifetime capital and operating costs combined into the levelized cost of energy (LCOE).

3.4 Simulation and Optimization

The simulation models use historical data for wind speed and sun irradiation to run under various circumstances. Particle swarm optimization (PSO) and genetic algorithms (GA) are two optimization techniques that are used to increase energy output, reduce expenses, and maximize efficiency.

3.5 Energy Storage Integration

In order to reduce intermittency, batteries are incorporated into the system. A model that balances battery life, storage capacity, and charge/discharge cycles is used to improve the storage system. The depth of discharge (DOD) and state of charge (SOC) of the battery are important factors in choosing the right size for energy storage.

4. ANALYTICAL APPROACH AND RESULTS

4.1 Energy Generation Analysis

The energy output from wind turbines and solar PV panels is displayed on a daily and monthly basis in the energy generation analysis. The average energy production from each source over the course of a typical month is shown in Table 1.

Table 1:Average Monthly Production of Energy (kWh)

Month	Solar PV Output (kWh)	Wind Turbine Output (kWh)	Total Energy Output (kWh)
January	450	320	770
February	470	340	810
March	500	360	860
April	520	380	900
May	600	400	1000
June	580	420	1000
July	550	450	1000
August	530	440	970
September	510	430	940
October	480	400	880
November	460	380	840
December	440	360	800

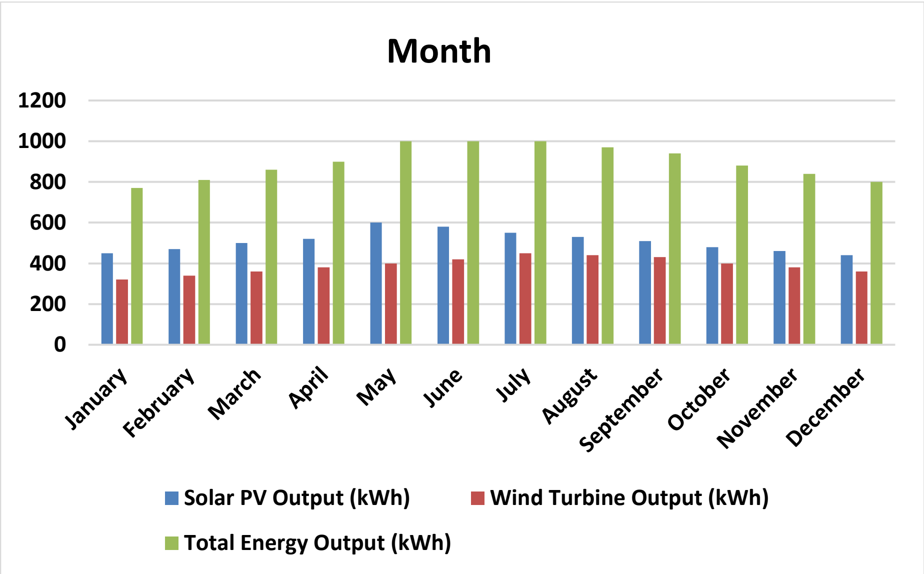

Figure 1:Graphical Representation on Average Monthly Production of Energy (kWh)

According to this data, the generation of energy is fairly balanced throughout the year, with wind turbines maintaining a constant output throughout windy seasons and solar PV contributing more during the summer.

4.2 System Efficiency

Efficiency is a crucial metric for evaluating the performance of the hybrid system. Energy generated vs available energy is used to calculate the total system efficiency. The system's efficiency both before and after optimization is shown in Table 2.

Table 2:System Performance Prior to and Following Optimization

Component	Efficiency (Pre-Optimization) (%)	Efficiency (post-optimization) (%)
Solar PV	16	19
Wind Turbine	27	32
Battery Storage	85	90
Overall System	71	80

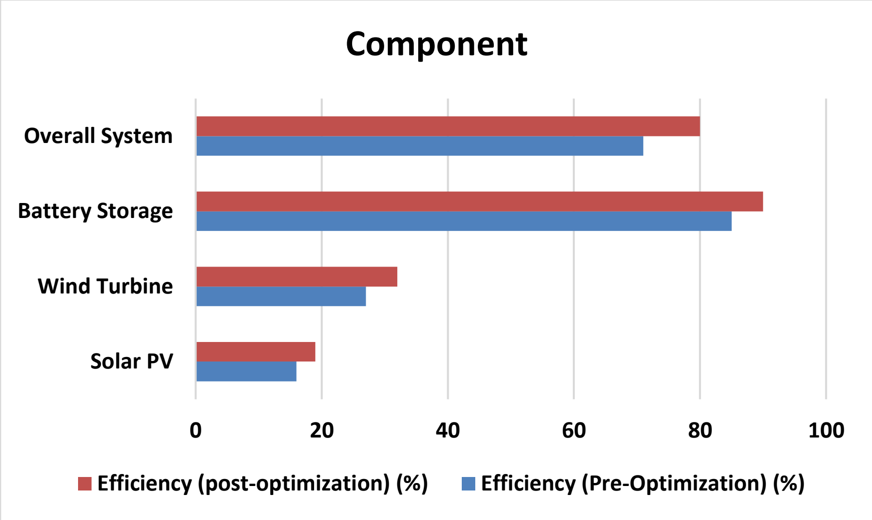

Figure 2: Graphical Representation on System Performance Prior to and Following Optimization

System efficiency was greatly increased by optimization techniques such modifying the tilt angle of solar panels and fine-tuning wind turbine control parameters. Higher energy conversion rates can be attributed to the usage of optimized algorithms such as PSO.

4.3 Economic Feasibility and Levelized Cost of Energy (LCOE)

The Levelized Cost of Energy (LCOE) is one tool used in economic research to assess the viability of a hybrid system. A cost comparison of different system configurations, such as PV-only, wind-only, and hybrid systems, is shown in Table 3.

Table 3:Comparing Various System Configurations' Levelized Cost of Energy (LCOE)

Configuration	CapEx ($/kW)	OpEx ($/kWh)	Total Energy Output (kWh/year)	LCOE ($/kWh)
PV-Only	1200	0.015	7200	0.14
Wind-Only	1400	0.012	8000	0.16
PV-Wind Hybrid	1600	0.010	9000	0.12

In areas with moderate to high wind speeds and solar irradiation, the hybrid system proves to be more economically viable over an extended period of time due to its lower level of cumulative cost of ownership (LCOE) as compared to standalone PV or wind systems.

5. CONCLUSION

The efficiency and performance of hybrid solar-wind energy systems present a strong answer to the problems associated with producing renewable energy, especially in areas with erratic weather. By combining energy storage devices, wind turbines, solar PV panels, and energy management technologies, hybrid power systems offer a more dependable and effective power source than standalone ones. When combined with thoughtful system design, optimization techniques like Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) greatly increase overall energy output, efficiency, and cost-effectiveness. This hybrid strategy is a promising option to meet the world's energy needs while lessening its impact on the environment because it not only encourages sustainability but also lessens reliance on fossil fuels.

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