American Journal of Energy and Natural Resources (AJENR)

ISSN: 2835-9186 (ONLINE)

VOLUME 4 ISSUE 1 (2025)

PUBLISHED BY

E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Energy and Natural Resources (AJENR)

Volume 4 Issue 1, Year 2025
ISSN: 2835-9186 (Online)
DOI: https://doi.org/10.54536/ajenr.v4i1.3684
https://journals.e-palli.com/home/index.php/ajenr

Design and Analysis of a Solar-Wind Hybrid Energy Generation System

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Article Information

Received: February 09, 2024

Accepted: September 27, 2024

Published: February 13, 2025

Keywords

Hybrid System, Renewable Energy, Solar Energy, Wind Energy

ABSTRACT

This paper explores how the increasing demand for renewable energy sources has resulted in the development of innovative technologies to harness solar and wind power. The paper evaluates the potential of solar wind hybrid power generation as a solution to address energy reliability, cost, and environmental sustainability challenges. The paper presents a system that generates electricity using wind and solar power, wherein an external high-speed fan rotates the rotor of a dynamo, producing magnetic flux that creates a DC voltage, and a solar panel absorbs photons of light, creating another DC voltage by freeing electrons. Both outputs are connected to a charge controller, a battery for energy storage, and a load, a motor with a propeller and an LED light. Two diodes ensure that the currents from the wind turbine and solar panel do not oppose each other. The paper also discusses various aspects such as pre-feasibility analysis, optimal sizing, modeling, control, and reliability issues related to the system.

INTRODUCTION

Energy is crucial for a country's development and economy. Bangladesh, a South Asian nation with around 170 million people, achieved a power generation capacity of 23,482 MW by February 2023, providing electricity to its entire population. The primary energy sources are natural gas (49.07%), furnace oil (26.74%), coal (11.46%), diesel (5.71%), hydro (0.98%), solar (1.1%), and 4.94% is imported from India (Khan & Nusrat, 2023). Due to global economic challenges and the finite nature of non-renewable energy, renewable sources like solar and wind power are increasingly vital. This clean, abundant Solar energy, a plentiful and renewable resource, comes from the sun's radiation. It can be captured through solar panels, thermal collectors, and concentrated solar power systems, transforming it into electricity, heat, and light. Wind energy is generated by wind movement using turbines, a renewable and sustainable source. It's clean and affordable, reduces reliance on fossil fuels, and helps lower greenhouse gas emissions and air pollution (Maka & Alabid, 2022). Hybrid energy systems combine multiple energy sources to produce electricity, addressing the limitations of relying on a single source. Solar energy is strongest during sunny days, while wind energy is more effective at night and in winter. By integrating these sources, hybrid systems offer continuous and reliable power, improving performance across various conditions (Hassan *et al.*, 2023).

A hybrid solar system offers continuous power by storing energy in batteries, which ensures uninterrupted electricity during outages or when the sun isn't shining. Unlike traditional systems, hybrids store excess solar energy, reducing waste and maximizing renewable energy use. This makes them more sustainable and eco-friendly. While the initial installation cost may be high, hybrid systems are cost-effective in the long term, as they don't require fuel or frequent maintenance, unlike generators. They operate efficiently in various weather conditions, reducing dependency on non-renewable energy and lowering the carbon footprint. Additionally, hybrid systems can adapt to specific power needs, providing a more efficient and reliable energy solution compared to conventional generators (Falope *et al.*, 2024).

Solar-wind hybrid power generation has gained momentum in recent years due to increasing awareness about climate change and the need to move towards sustainable energy sources. The decreasing costs and advances in technology have also contributed to making solar-wind hybrid power systems more competitive with traditional fossil fuel-based power sources (Olabi *et al.*, 2023). There is a growing demand for renewable energy, and this has led to increased investment in the development and deployment of hybrid systems, which are being supported by governments and private companies (Khare *et al.*, 2016).

This research aims to design and implement a simulation model for solar-wind hybrid energy generation, analyze its efficiency with Simulink and physical tests, verify system stability, assess the feasibility of solar and wind resources, and demonstrate the efficiency of the hybrid energy system.

LITERATURE REVIEW

In this project, a hybrid system combining solar and wind energy is developed, where the power generated from these sources is directed to a DC circuit and stored in a battery. The output from each source is variable; for instance, the turbine's rotation speed fluctuates based on wind velocity. The wind energy generation setup is positioned in the middle of a lightweight pole. Lightweight

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blades are utilized to enable rotational motion even at low wind speeds. Similarly, the solar output varies with the intensity of sunlight. The operational process of the hybrid power system is depicted in the flow chart below.

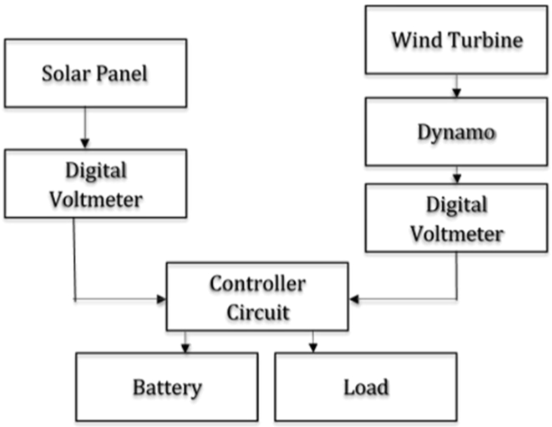

Figure 1: Flow chart of the hybrid system

Bhave A.G researched the feasibility of a solar-wind hybrid system using lead-acid batteries for storage and AC mains for backup power. The study found that the hybrid system met 80% of energy needs. However, its cost-effectiveness relied on significantly lowering system costs or raising current electricity prices (Farooq *et al.*, 2024).

An analysis was conducted on a wind-photovoltaic system with battery storage, intended for grid connection via a rooftop setup. The system aimed to meet typical load demands while addressing the risk of power supply interruptions. The study evaluated factors including system reliability, power quality, supply loss, and the effects of the variable nature of wind and solar radiation on the design. The results showed that the wind and solar components complemented each other, enhancing overall system reliability (Mohamed *et al.*, 2022).

Celik proposed a new optimization approach for conducting a techno-economic evaluation of autonomous small-scale photovoltaic wind hybrid energy systems. The technique enables the identification of an optimal combination of photovoltaic and wind energy systems that can enhance overall system performance compared to either system operating alone. The research demonstrated that the battery storage capacity has a significant impact on the performance of a single photovoltaic or wind energy system (Celik, 2003). Yang and their team introduced an optimization method that incorporates the Loss of Power Supply Probability model to enhance the reliability of a hybrid photovoltaic-wind energy system. The research illustrated the practicality of this model through a case study that focused on a hybrid system designed for a telecommunication application (Yang *et al.*, 2007). A techno-economic analysis and optimization were conducted of a photovoltaic-wind hybrid system and compared the results with a standalone solar and wind system that was designed to meet the same load, isolation, and wind velocity requirements. Previous studies had designed the system based on the worst month, which resulted in a non-optimal and expensive system in terms of techno-economics. In the current research, an alternative method was employed that involved incorporating a third energy source into the system instead of excessively increasing the hardware sizes to address the worst month. This approach facilitated the development of a more economically feasible system (Belmili *et al.*, 2014). Bitterlin I.F. has developed a model for a reliable power system for a remote radio base station, using a combination of wind, photovoltaic, and storage technologies. The study aimed to explore the practicalities of using a hybrid power generation solution, specifically for cellular phone base stations. The research showed that the use of photovoltaic power generation is not technically or commercially viable for this application due to the need for a large capacity of PV modules and batteries. However, wind power generation is technically feasible and has some practical possibilities when integrated with the radio mast. Due to the longer-term intermittence of the wind, a backup power supply is necessary, and a diesel generator is found to be the best option. The battery system helps to minimize the start/run demand on the diesel engine, which in turn reduces the required size of the battery storage capacity (Bitterlin, 2006).

MATERIALS AND METHODS

Developing a hybrid power generation system involves integrating solar and wind energy sources to meet energy demands. This hybrid system optimizes the use of available solar and wind resources, ensuring efficient energy utilization and enabling effective power control.

Solar panels consist of photovoltaic cells, typically silicon, that absorb sunlight energy. Wind turbines convert wind's kinetic energy into electricity using tall-mounted structures. The charge controller adjusts the solar panel's voltage to prevent battery overcharging or undercharging, protecting its capacity and lifespan (Layth *et al.*, 2019).

Figure 2: Charge Controller

The charge controller manages the current between solar panels and the battery, ensuring optimal charging rates to prevent damage from overcharging or undercharging.

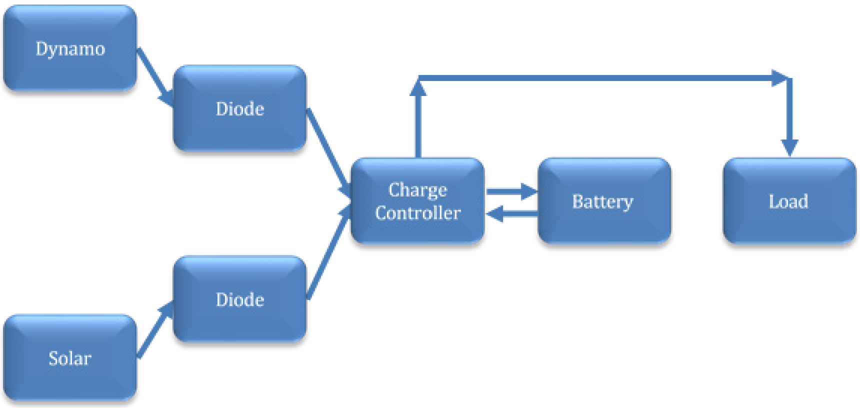

Figure 3: Block Diagram of Solar Wind Hybrid Energy System

This charge controller monitors battery voltage and temperature, adjusting or disconnecting the solar panel to protect the battery. Some controllers also regulate power output to devices, preventing over-discharge and extending battery life. Excess electricity from sources like solar panels or wind turbines is stored in a battery by converting it into chemical energy.

In a solar-wind hybrid system, components are integrated to work together in generating electricity. Solar panels and wind turbines are typically connected in parallel to a power inverter, which converts the DC electricity produced into AC electricity for the electrical grid or battery storage.

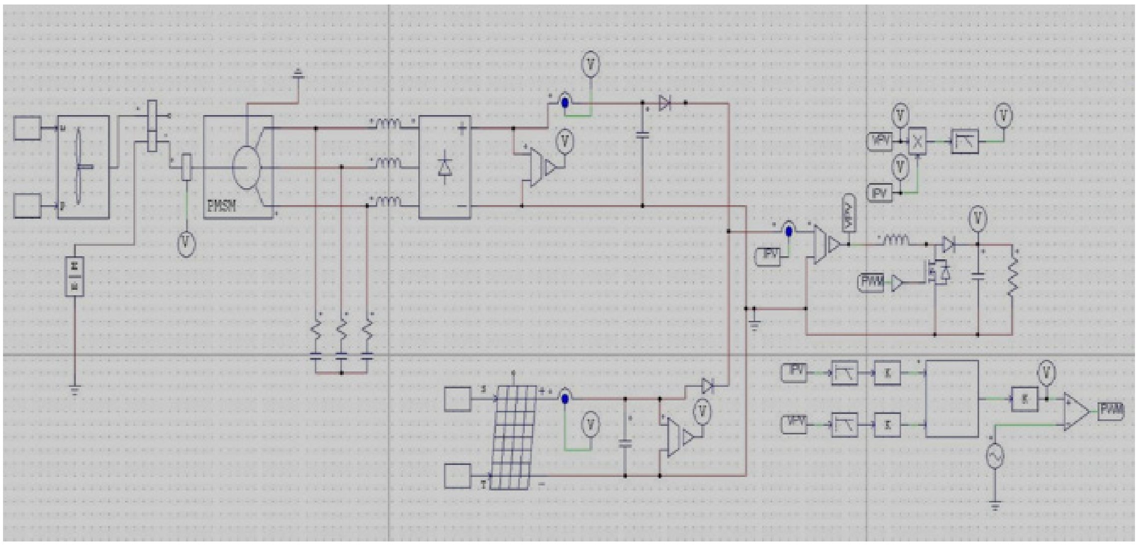

Figure 4: Circuit Diagram of a Solar Wind Hybrid Energy Generation System

RESULTS AND DISCUSSION

A power management system oversees the operation, ensuring optimal efficiency and effective use of generated electricity. Additionally, a battery storage system can be included to store excess energy during peak production for later use. The power inverter and management system also control and monitor the battery's charging and discharging processes.

The effectiveness of such a system depends on factors like its size, location, and technology used. These two renewable sources often complement each other, as wind power can generate electricity when solar production is low and vice versa. This synergy can make a hybrid system more efficient than single-source systems, such as during cloudy periods when wind turbines might produce more energy. Additionally, a hybrid system may be more cost-effective to install and maintain, as it allows for shared components like wiring and support structures.

A fan has been used as the source of wind to rotate the rotor of the dynamo so that there can be produced magnetic flux in the rotor coil. The induced magnetic flux from the rotor coil cut the permanent magnetic flux produced in the stator. As a result, we get a DC voltage. On the other hand, we have used a solar panel where we get energy from the photons of light. At this point, we get a DC voltage as output. We have to connect the outputs from the wind turbine and solar panel by parallel connection and then connect it to the charge controller. Here we use two diodes in the output of the wind turbine and solar panel before the charge controller, so that, the current from the solar and wind turbine cannot oppose each other. We have two output connections from the

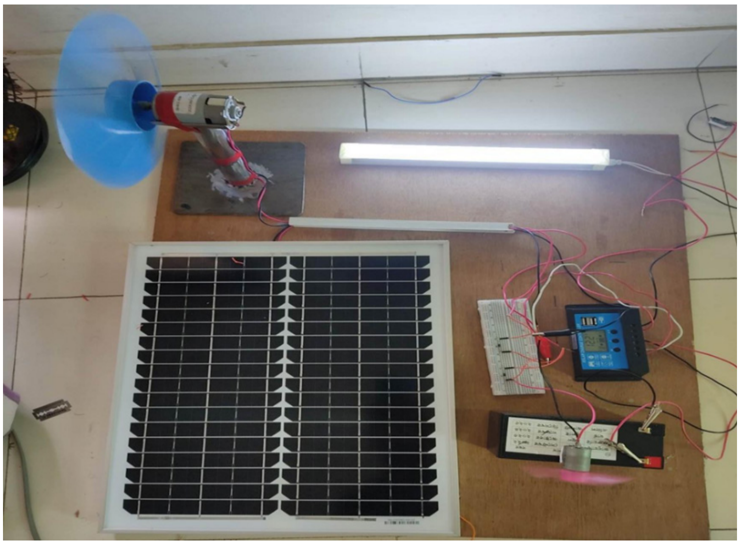

Figure 5: Prototype of Solar Wind Hybrid Energy Generation

charge controller. We use a battery to store energy and other output goes to a load directly. Here we use a motor as a load. We connect a propeller to the motor. So, the load works here as a fan. Again, we connect an LED light as a load with the battery. Our connection has been done at this point.

Table 1 presents the ratings and real-time data of the wind-solar hybrid power generation system that was created, and provides a summary of the conclusions drawn from the results.

Table 1: PV Array Data

Maximum Power (W) =	20 W
Open-Circuit voltage =	22.4 V
Short-Circuit Current =	1.23 A
voltage at maximum power point =	17.4 V
Current at maximum power point =	1.15 A

Here, we got a maximum of 19.6W power from the PV array where we can see that 0.4 W is system loss. The voltage, we got, was 21V and the current was 0.92A.

Table 2: Wind Turbine Data

Maximum Power (W) =	400 watt
Voltage =	220 V
Current =	1.81 A
Speed =	15600 rpm
Torque =	1131 g.cm

A maximum 32V voltage has been found from the wind turbine. As we have a low wind source, we did not get the voltages more than 32V. Here the output current was 0.52A. We had 32V voltage in the charge controller when we connected the solar panel and the wind turbine in parallel

Limitation

Solar-wind hybrid energy systems require specific site conditions, such as adequate wind speeds and sufficient solar radiation, limiting their feasibility to certain locations. They are not ideal for regions with low wind or solar resources and usually demand considerable land area. The cost of installing and setting up these systems is generally higher than for standalone solar or wind systems due to the additional components needed, including turbines, solar panels, inverters, and specialized equipment (Jamshidi *et al.*, 2021). Managing a solar-wind hybrid system is more complex because it involves integrating two distinct energy sources, which can lead to increased maintenance expenses and a need for specialized technical skills. Regular cleaning and repairs of system components, like turbines and solar panels, further add to the cost and effort. Additionally, since solar and wind energy are both weather-dependent, the power output can be inconsistent, requiring energy storage solutions to maintain a steady supply. This requirement for storage increases the overall system cost and necessitates ongoing battery maintenance and monitoring (Hassan *et al.*, 2023). Despite these challenges, solar-wind hybrid systems remain a viable and sustainable energy solution, and this thesis aims to enhance understanding and support the implementation of these systems for a more sustainable and secure energy future.

CONCLUSION

The solar-wind hybrid power generation system offers a promising approach to improving energy security, promoting environmental sustainability, and boosting economic efficiency. By integrating both solar and wind power, this hybrid system delivers a more consistent and reliable energy supply, as the complementary characteristics of these sources help to mitigate fluctuations in output. Additionally, it can significantly reduce greenhouse gas emissions and minimize the environmental impacts linked to traditional energy production.

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