Performance Analysis of Solar Wind Hybrid Energy System Using Mppt Control

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Abstract—**The growing global demand for clean and reliable electricity has intensified the need to shift from conventional fossil-fuel–based generation to renewable energy sources. Solar and wind energy are abundant, pollution-free and sustainable, yet each suffers from variability due to changing environmental conditions. To address this limitation, this paper presents a Solar–Wind Hybrid Energy System (SWHPS) integrated with a Maximum Power Point Tracking (MPPT) technique. By combining photovoltaic panels and a wind turbine in a parallel configuration, the system ensures continuous power availability, allowing one source to compensate when the other becomes insufficient. The MPPT controller, implemented using the constant-voltage method and a PIC18F452 microcontroller, optimizes power extraction under varying irradiation and wind-speed conditions. Experimental results demonstrate improved voltage stability and efficient power transfer, The study concludes that the hybrid system enhances performance, reliability and scalability compared to standalone systems, making it suitable for practical applications in remote and off-grid regions.**

Index Terms—**Solar energy system, Wind energy system, Hybrid energy system, MPPT Controller, Battery.**

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I. INTRODUCTION

The increasing global demand for electrical energy, combined with the fast depletion of fossil fuel reserves, has intensified the search for clean, sustainable, and reliable alternative energy sources. Conventional fuels not only contribute to environmental pollution but also face long-term availability issues, making renewable energy a vital component of modern power-generation strategies. Among the available renewable resources, solar and wind energy have emerged as highly promising due to their abundance, accessibility, and eco-friendly nature. However, using either source alone often fails to provide consistent power output, mainly because solar radiation and wind speed vary significantly with changes in weather, time of day, and seasonal patterns. To overcome such intermittency, researchers have increasingly focused on hybrid renewable energy systems that combine solar and wind sources. Solar radiation and wind profiles tend to complement each other; sunlight is typically stronger during summer and daytime, while wind speeds often increase during night-time or winter. A Solar–Wind Hybrid Energy System (SWHPS) therefore enhances reliability by ensuring that when one source underperforms, the other can compensate. This makes hybrid systems particularly suitable for remote or rural areas where grid connectivity is limited and consistent power supply is essential.

With advancements in power electronics, the integration of photovoltaic (PV) units and wind turbines has become more efficient and practical. However, because both energy sources are inherently variable, their power output must be optimized through intelligent control techniques. Maximum Power Point Tracking (MPPT) plays a crucial role in extracting the highest possible power from the system under different environmental conditions. In this project, the constant-voltage MPPT method is employed along with a PIC18F452 microcontroller to stabilize the hybrid output and ensure consistent energy delivery.

By connecting both sources in parallel and utilizing a dedicated control and conversion stage, the hybrid system delivers regulated power to the load or battery bank. Overall, the Solar–Wind Hybrid Energy System provides an efficient, reliable, and scalable solution for

clean energy production, offering significant advantages over standalone renewable systems.

II. LITERATURE REVIEW

Solar–wind hybrid energy systems have received significant research attention as a solution to the inherent intermittency of individual renewable sources. Castillo et al. (2015) developed a low-cost solar–wind hybrid prototype and demonstrated that combining these two naturally complementary sources improves power availability in remote regions. Their work emphasized the feasibility and practical benefits of hybrid integration. Kumar et al. (2015) proposed an MPPT controller using fuzzy logic for hybrid systems, showing that advanced control algorithms substantially increase power extraction efficiency under varying temperature, solar irradiation, and wind speed conditions.

Rini and Razzak (2015) investigated voltage and power regulation in hybrid setups and highlighted the importance of using MPPT controllers to maintain stable output. Their findings support implementing constant-voltage and other MPPT methods to optimize energy transfer in fluctuating environments. Pavan Kumar et al. (2014) analysed the behaviour of PV cells using two-diode modelling, which is crucial for enhancing MPPT algorithm accuracy in hybrid systems

Further research by Zargar et al. (2016) incorporated energy storage into hybrid configurations, demonstrating improved reliability and continuity of supply through efficient MPPT-based control. Patsamatla et al. (2014) introduced a universal MPPT strategy capable of handling both wind and solar inputs simultaneously, making hybrid systems more adaptable and effective. Liwen et al. (2012) presented simulation-based studies of hybrid topologies, confirming that hybridization strengthens system stability across seasonal variations.

Studies by Natsheh et al. (2011) and Tiwari et al. (2016) further explored hybrid system integration within smart grid and micro-grid frameworks, reinforcing the growing role of MPPT-enhanced hybrid systems in future energy networks.

Overall, existing literature consistently supports that solar–wind hybrid systems, when combined with efficient MPPT techniques, offer superior performance, higher reliability, and improved energy utilization compared to standalone renewable energy systems.

III. METHODOLOGY

The proposed solar–wind hybrid energy system operates through three major stages: power generation, conversion/control, and distribution. In the generation stage, the solar photovoltaic panel produces DC power, while the wind turbine generates AC power. The AC output is converted to DC using a rectifier so both sources can be combined. This combined DC power is then fed into an MPPT controller implemented using the PIC18F452 microcontroller. The controller uses the constant-voltage MPPT technique to sense input voltage, track the maximum power point, and regulate the output voltage. Finally, the stabilized and optimized power is supplied directly to the load or stored in a battery for later use, ensuring reliable and continuous energy availability.

1. Solar Panel Formulas

a) Output Power of Solar Panel

$$P_{solar} = V_{pv} \times I_{pv}$$

b) Maximum Power Point (MPP)

$$P_{mpp} = V_{mpp} \times I_{mpp}$$

c) Open-circuit Voltage and Short-circuit Current

$$V_{oc} = \text{open circuit voltage}$$

$$I_{sc} = \text{Sshort circuit current}$$

2. Wind Turbine Power Formula

Wind turbine mechanical power:

$$P_{wind} = \frac{1}{2}\rho A C_p v^3$$

3. Hybrid System Total Power

$$P_{total} = P_{solar} + P_{wind}$$

4. DC Power After Rectifier (From Wind)

$$P_{dc} = V_{dc} \times I_{dc}$$

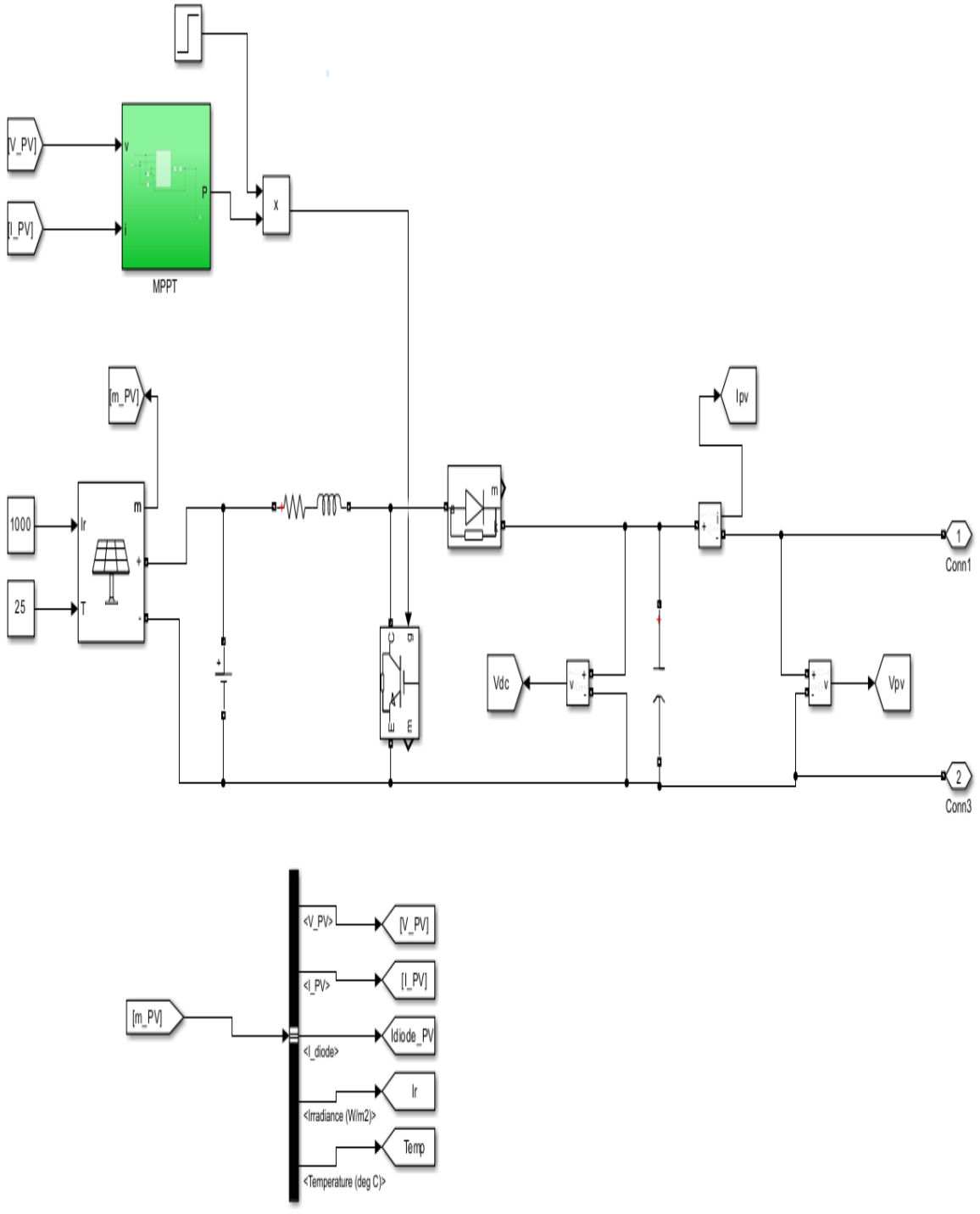
5. Battery Charging Power

$$P_{battery} = V_{battery} \times I_{battery}$$

6. Efficiency of the Hybrid System

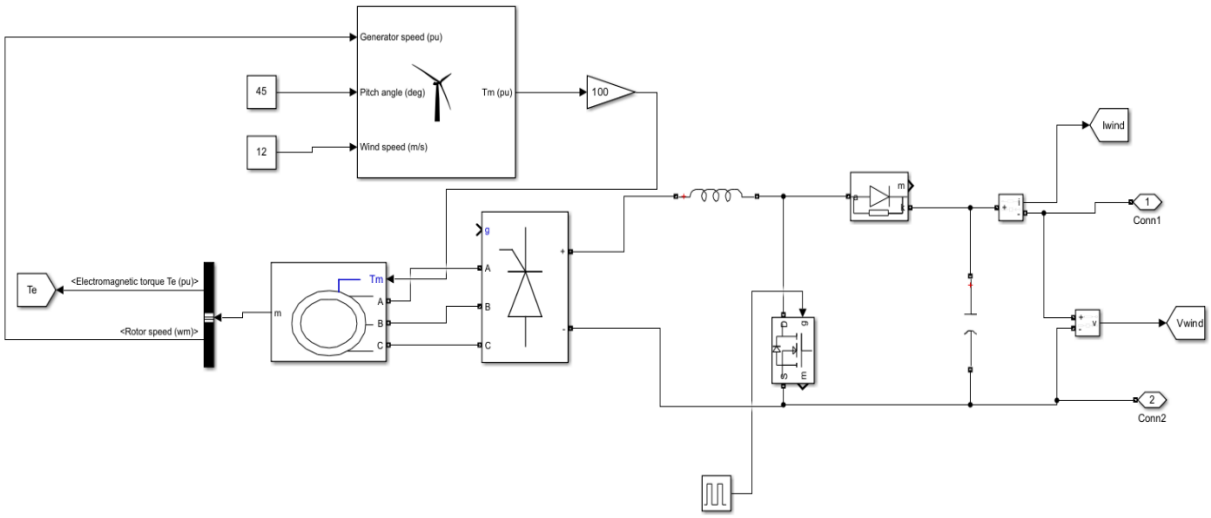
$$\eta = \frac{P_{output}}{P_{input}} \times 100$$

IV. SIMULATION RESULTS



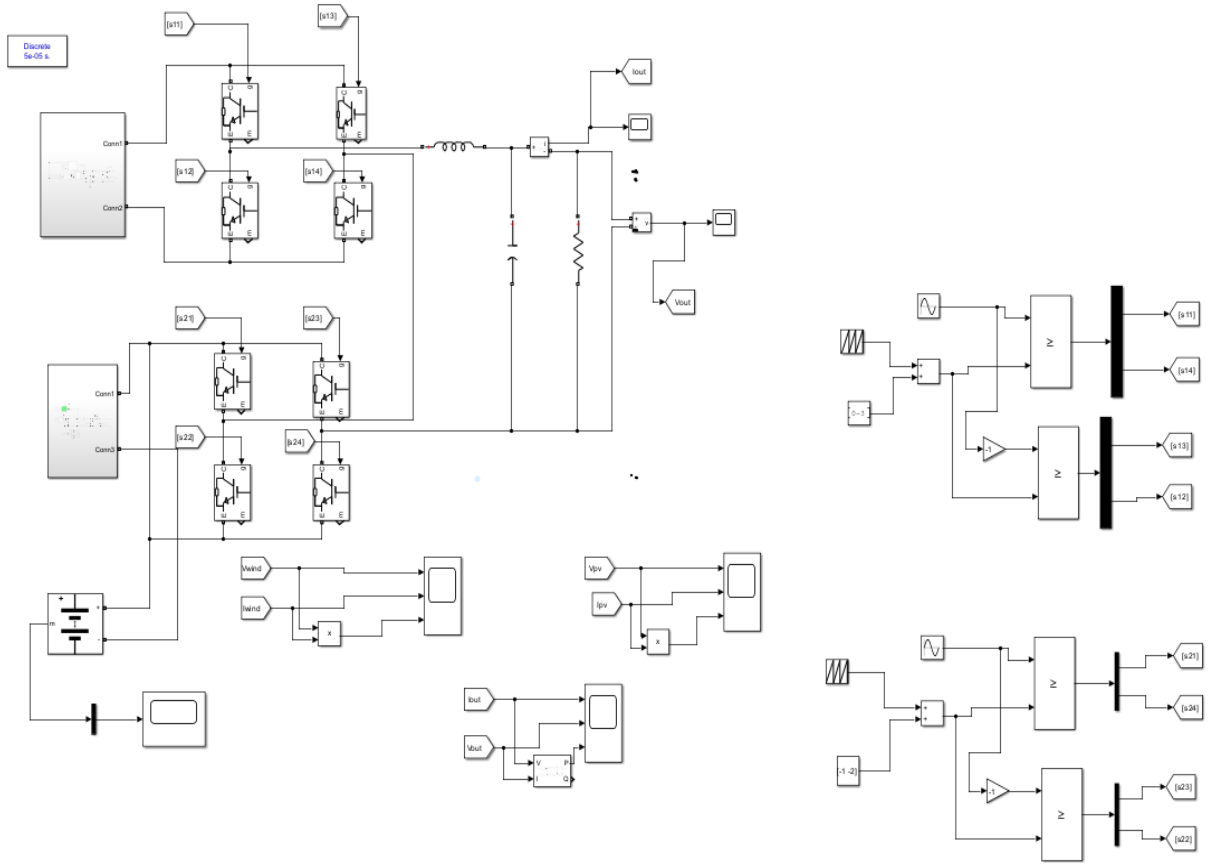
(a) Solar PV System Using MPPT Controller

The PV array generates DC power based on irradiance and temperature. The MPPT controls the dc-dc converter to extract maximum power from the PV array. The output is connected to a load or inverter through measurement blocks.



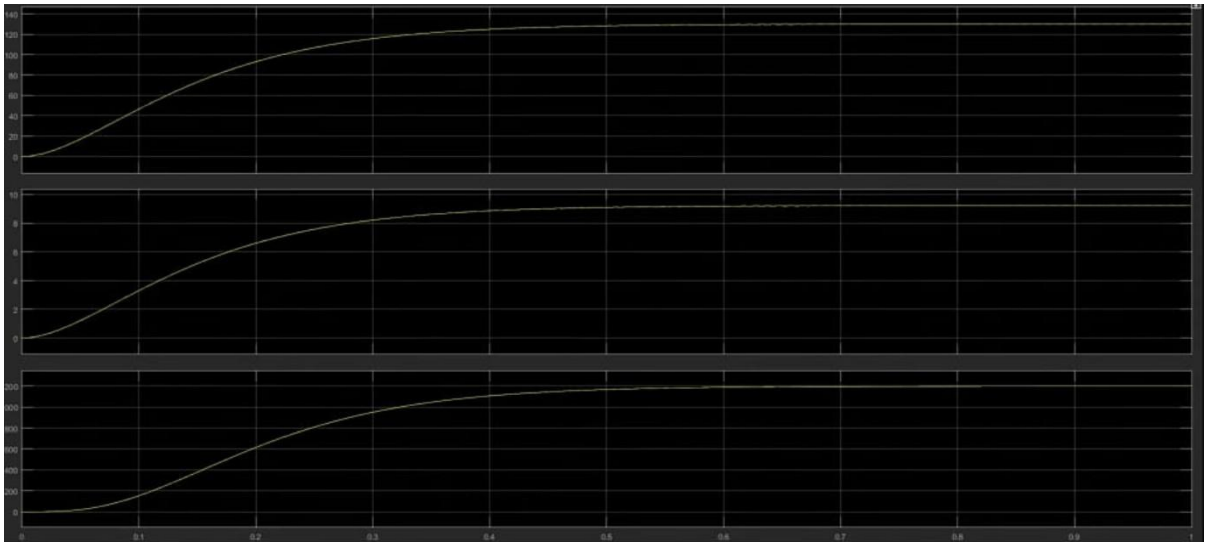
(b)Wind Energy Conversion System

The wind turbine block models wind speed, pitch angle and generator speed. The PMSG converts the mechanical power of the turbine into Ac electrical power. The rectifier converts the AC output of the generator into DC. Measurement blocks display wind voltage, current, and power.



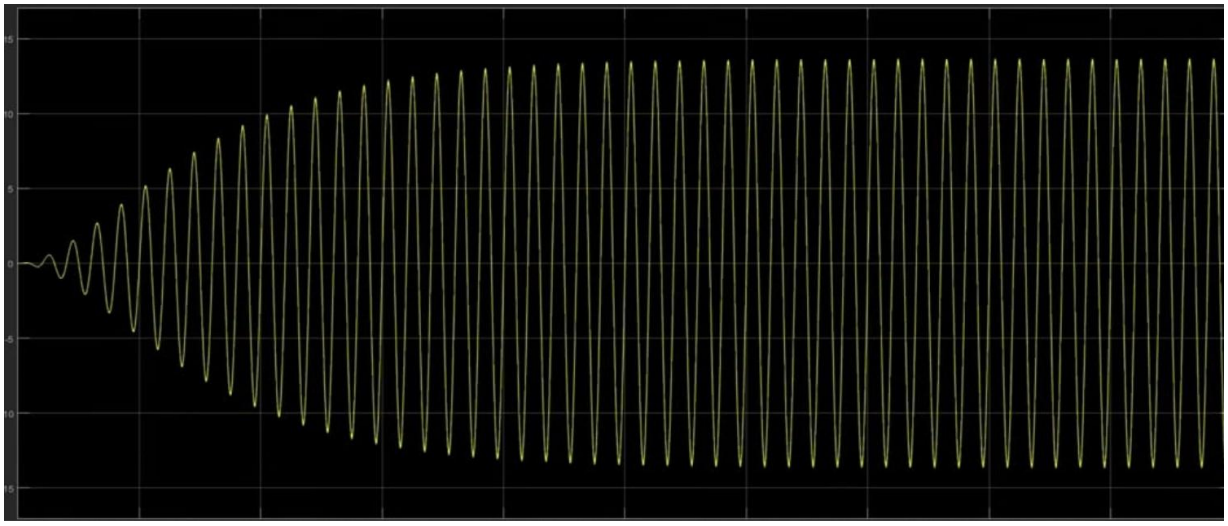
(C) Performance analysis of solar wind hybrid energy system using mppt control

This Simulink model represents a hybrid renewable energy system combining wind and solar power. It includes converters, switches, measurement blocks, control circuits, and output monitoring for voltage, current, and power.



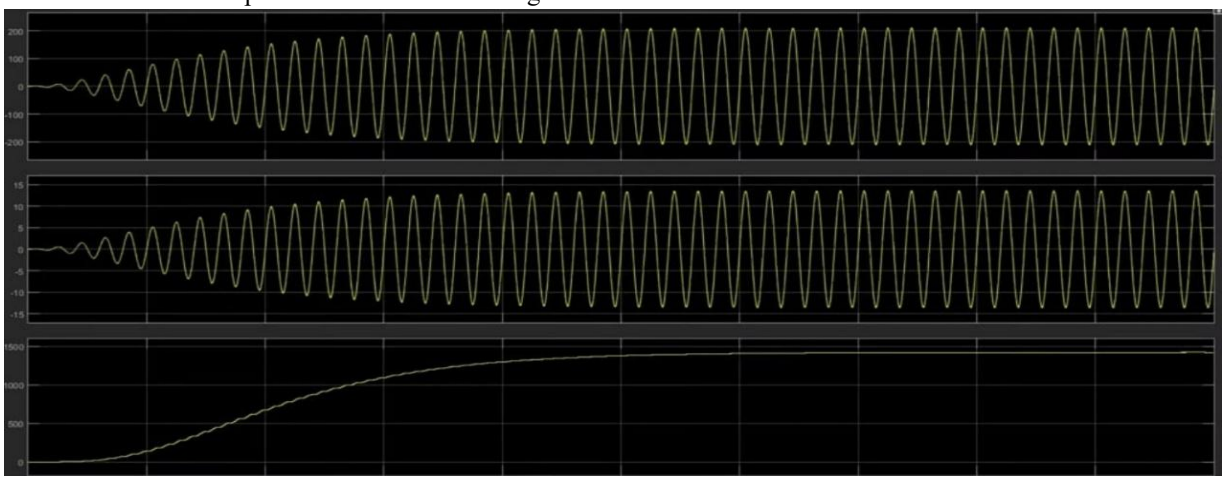
(D)Solar and Wind DC Output Graphs

Graph		Final Value	Behavior
1st graph		140	rises then stabilizes
2nd graph		10	smooth rise, small ripple
3rd graph		1500	fast rise, stabilizes



(E)AC Output Voltage Graph

- Sinusoidal AC waveform
- Frequency looks constant
- Amplitude is small at the start, then gradually increases, then stays constant
- Looks like a start-up transient of an inverter / generator / AC machine



(F)Solar and Wind AC Output Graphs

Graph	Final Value	Type
Voltage waveform	±200 V	AC sinusoid, steady amplitude
Current waveform	±17 A	AC sinusoid
Output quantity	1500	Power / Torque / DC Link / MPPT output

V. CONCLUSION

The solar–wind hybrid energy system using MPPT effectively demonstrates a sustainable and efficient solution for meeting modern power demands. By combining two complementary renewable resources, the system ensures continuous energy generation throughout varying environmental conditions. The MPPT controller enhances system performance by extracting maximum possible power, maintaining stable voltage, and improving overall efficiency. Experimental results confirm that the hybrid setup delivers more reliable output compared to individual solar or wind systems, especially during fluctuating weather.

This approach also reduces dependency on fossil fuels, lowers operational costs, and supports clean energy goals. The scalability of the system allows easy expansion by adding more PV panels, wind turbines, or battery storage. Overall, the project highlights a practical and eco-friendly method for generating uninterrupted renewable power suitable for households, remote areas, and small-scale applications.

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