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Eco charge Hub: A Sustainable Power Station using Hybrid Renewable Energy

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Abstract

The increasing global demand for clean energy and the rapid growth of electric vehicles (EVs) have intensified the need for sustainable and reliable charging infrastructure. Conventional fossil fuel–based power generation contributes significantly to environmental pollution and climate change, motivating the adoption of renewable energy solutions. This paper presents the design and implementation of an Eco Charge Hub, a hybrid renewable energy–based charging station that integrates solar and wind energy sources to provide continuous and eco-friendly power for charging electronic devices and small-scale EV applications. The proposed system combines photovoltaic (PV) panels and a wind energy system with battery energy storage and power electronic converters to ensure uninterrupted energy supply under varying environmental conditions. An energy management approach prioritizes renewable energy utilization and stabilizes output power. The developed prototype demonstrates reliable charging performance, scalability, and suitability for off-grid and urban public installations. The Eco Charge Hub offers a practical and sustainable solution for promoting green energy adoption and supporting future electric mobility infrastructure.

Keywords: Hybrid Renewable Energy, Solar Power, Wind Energy, Eco Charge Hub, EV Charging Station, Battery Energy Storage System.

1. Introduction

The continuous rise in global energy consumption and the adverse environmental impact of fossil fuel–based power generation have created an urgent need for clean, renewable, and sustainable energy solutions. Renewable energy sources such as solar and wind power have emerged as promising alternatives due to their abundance and minimal environmental impact. However, the intermittent nature of individual renewable sources often limits their reliability when used independently.

The rapid growth of electric vehicles (EVs) further increases the demand for reliable and environmentally friendly charging infrastructure. To address these challenges, hybrid renewable energy systems that combine multiple energy sources offer improved reliability, efficiency, and energy availability. By integrating solar and wind energy, a hybrid system can generate power during both daytime and low-light or nighttime conditions, reducing dependence on a single source.

This paper proposes an Eco Charge Hub, a hybrid solar–wind renewable energy–based charging station designed to provide clean and sustainable power for charging electronic devices and supporting future EV charging needs. The system aims to reduce carbon emissions, promote green energy usage, and provide an effective off-grid or grid-assisted charging solution suitable for campuses, highways, and community spaces.

2. Literature Review

Several studies have explored renewable energy–based charging systems for electronic devices and electric vehicles. Solar and wind energy–based charging stations for EVs have been modeled and simulated using power electronic converters and energy management strategies, highlighting the importance of hybrid architectures for improved reliability. However, many studies focus primarily on simulation-based validation and lack practical hardware implementation.

Portable green energy charging systems integrating solar panels and small wind generators have demonstrated feasibility at a small scale, emphasizing real-world fabrication challenges such as portability, efficiency, and cost. Other research works propose hybrid solar–wind charging stations for campuses and highways, focusing on system architecture and basic sizing methodologies.

Hybrid Renewable Energy Systems (HRES) combining photovoltaic panels, wind turbines, and battery energy storage systems have been shown to achieve higher renewable energy utilization and lower cost of energy compared to single-source systems. Effective energy management systems and battery storage play a crucial role in ensuring stable power delivery, especially for EV charging applications. Despite these advancements, there remains a need for practical, scalable, and cost-effective hybrid charging solutions with real-world implementation and performance evaluation.

Several previous studies have investigated renewable energy–based charging systems. Chellaswamy et al. [1] and Manikyalrao et al. [2] analyzed hybrid solar–wind charging station architectures, primarily through simulation and design-based approaches. Portable renewable charging systems were experimentally demonstrated in [3] and [4], focusing on small-scale applications. Automatic solar tracking techniques have been shown to improve photovoltaic efficiency as reported in [5], [6]. However, most existing works lack a fully integrated hybrid system with experimental validation and tracking-based optimization. The present work addresses these gaps through the implementation and testing of a hybrid solar–wind Eco Charge Hub with automatic solar tracking.

3. System Architecture and Design

The proposed Eco Charge Hub integrates solar and wind energy sources with a battery storage system and power electronic converters to provide reliable charging output. Fig. 1 illustrates the overall architecture of the system.

3.1 Solar Energy Subsystem

The solar energy subsystem consists of an 80 W photovoltaic panel rated at 18 V DC. The panel converts solar radiation into electrical energy using the photovoltaic effect. The generated DC power is supplied to a charge controller, which regulates the charging of the battery and prevents overcharging or reverse current flow.

3.2 Automatic Solar Tracking System

In Fig 1. illustrates the Arduino-based automatic solar tracking system employed to maximize solar energy extraction.To enhance solar energy harvesting, an automatic solar tracking system is implemented using an Arduino Uno microcontroller, LDR sensors, and a DC geared motor. Two LDR sensors detect variations in light intensity, and the Arduino generates control signals to rotate the solar panel toward maximum illumination. Experimental observation shows improved energy capture compared to a fixed panel configuration.

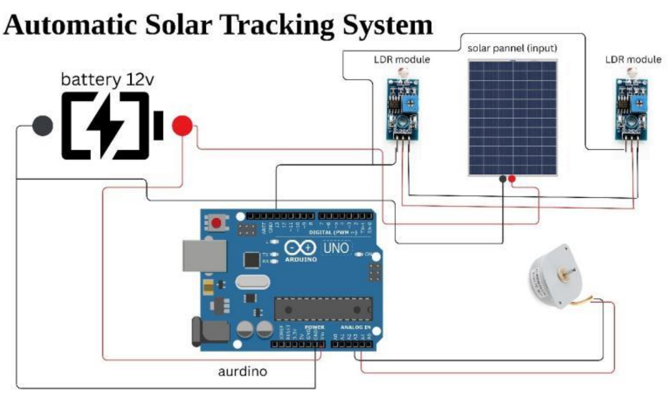

Fig 1. Block diagram of Arduino-based automatic solar tracking system using LDR Sensors

3.3 Wind Energy Subsystem

The wind energy subsystem complements the solar source by generating power during low-light or nighttime conditions. The wind turbine output is conditioned and integrated into the system to improve overall energy availability and reliability.

3.4 Battery Energy Storage System

A 12 V, 40 Ah rechargeable battery is used to store excess energy generated from renewable sources. The battery ensures continuous power supply during periods of low solar irradiance or wind speed. The stored energy supports uninterrupted charging and enhances system reliability.

3.5 Power Conditioning and Output Units

DC–DC buck converters are employed to step down the battery voltage to a regulated 5 V DC output for USB charging ports. A DC–AC inverter converts the 12 V DC battery output to 220 V AC, enabling laptop charging and small AC loads. Switches and protection devices are incorporated for safe operation.

4. Hardware Implementation

The complete hardware prototype of the Eco Charge Hub was developed using commercially available components. Mechanical structures were fabricated for mounting the solar panel and tracking mechanism. Electrical wiring was carried out according to the designed circuit, integrating renewable sources, battery storage, control units, and output interfaces. Safety measures such as fuses and switches were incorporated to ensure reliable operation.

5. Methodology

The development of the Eco Charge Hub follows a systematic methodology:

System Planning and Requirement Analysis: Estimation of energy demand and assessment of available solar and wind resources.

Component Selection: Selection of solar panels, wind turbine, battery, charge controller, inverter, and converters based on efficiency and compatibility.

System Design and Integration: Integration of renewable sources, battery storage, and power electronics into a unified system.

Hardware Development: Assembly of mechanical structures and electrical wiring with appropriate safety measures.

Testing and Evaluation: Performance testing under varying environmental and load conditions to assess reliability and efficiency.

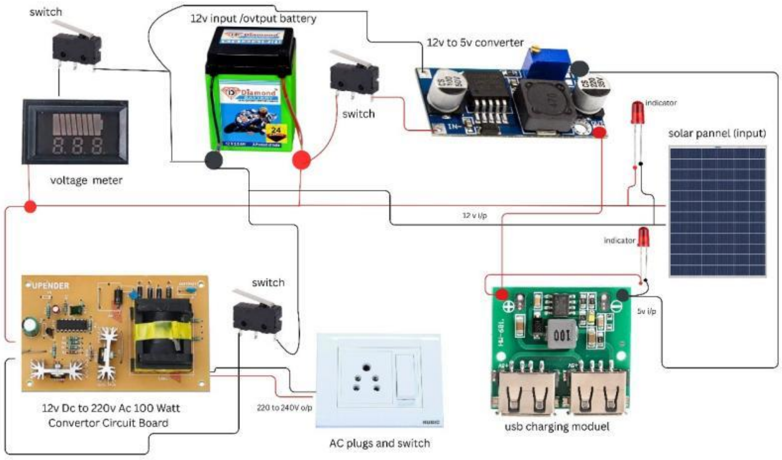

Fig 2. Wind and Solar power laptop and mobile charging

6. Experimental Setup and Testing

The Eco Charge Hub prototype was fully implemented and experimentally tested under real operating conditions. The system integrates a solar panel with an automatic solar tracking mechanism, wind energy input, battery energy storage, and multiple charging outputs. The experimental setup includes an Arduino-based control unit, LDR sensors for solar tracking, a DC motor for panel movement, a charge controller, inverter, and USB charging modules. Testing was carried out under different environmental conditions, including sunny, partially cloudy, and low-light scenarios. Key parameters such as battery voltage, charging current, solar panel alignment, and load performance were monitored. The system was tested for mobile phone charging, laptop charging, and continuous operation over extended duration's to validate reliability and stability.

6.1 Functional Testing

The solar tracking mechanism was tested by exposing the system to varying light directions. The panel successfully rotated toward higher light intensity. Battery charging and load switching operations were verified.

6.2 Performance Testing

The system was tested for mobile phone and laptop charging. Output voltage stability and continuous operation were monitored over extended duration's.

6.3 Environmental Testing

Testing was conducted under sunny and partially cloudy conditions. The hybrid configuration ensured uninterrupted operation despite variations in solar irradiance.

7. Results and Discussion

The experimental results confirm that the developed Eco Charge Hub operates reliably under varying environmental conditions. The automatic solar tracking system successfully aligned the photovoltaic panel toward maximum light intensity, resulting in improved energy capture compared to a fixed-panel configuration. The battery energy storage system ensured uninterrupted power delivery during periods of low solar irradiance and wind availability. Mobile devices and laptops were charged efficiently through USB and AC outputs, respectively, with stable voltage levels observed throughout operation. The hybrid solar–wind configuration enhanced system reliability by compensating for fluctuations in individual renewable sources. Overall, the results demonstrate that the implemented system is suitable for small-scale charging applications and can be scaled for higher power requirements, including electric vehicle charging infrastructure.

Table I: Experimental Test Results

Parameter	Observed Value
Battery Voltage	12–13.2 V
Battery Charging Current	1.8 – 3 A
USB Output Voltage	5 V
USB Output Current	Up to 2 A
AC Output Voltage	220 V
Inverter Efficiency	~85–88%
Solar Tracking Response	Successful
Solar Power Gain (Tracked vs Fixed)	~20–30% increase
Wind Turbine Output Voltage	12–18 V (variable)
Charging Devices	Mobile Phones, Laptops
System Operation	Stable under varying conditions

- The system maintained thermal stability, with no excessive heating observed in the inverter and charging modules.
- The charge controller successfully prevented battery overcharging and deep discharge.
- The Eco Charge Hub operated reliably in outdoor environmental conditions, validating its suitability for public and remote charging stations.

Fig 3. Battery voltage display during charging

Fig 4. USB Charging Ports for Mobiles and Laptops

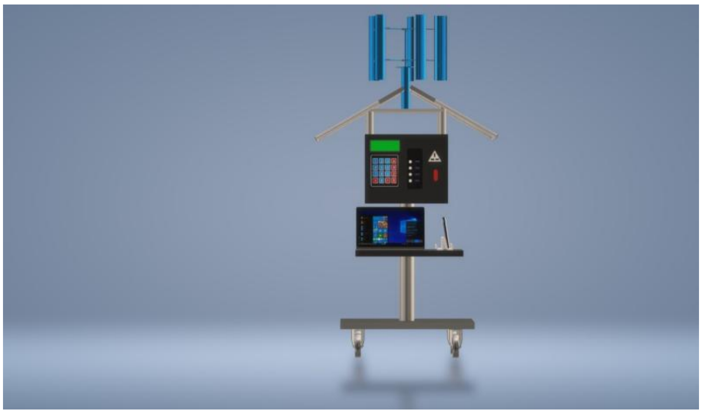

Fig 5. Complete Eco Charge Hub prototype setup

8. Limitations and Future Scope

The current prototype supports small-scale charging applications and is limited by battery capacity and environmental dependence. Future work includes scaling the system for full EV charging, integrating IoT-based energy management, and enabling vehicle-to-grid (V2G) functionality.

9. Conclusion

This paper presented the design, implementation, and experimental validation of an Eco Charge Hub based on a hybrid solar–wind renewable energy system. The completed and tested prototype demonstrates reliable, eco-friendly, and scalable charging performance. The results confirm the feasibility of hybrid renewable energy–based charging stations as a sustainable solution for future electric mobility infrastructure.

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