

Development of Hybrid Solar Tracking, Wind and AC Mains Based Charging Station with Intelligent Power Management

Dr. M. S. Matey

Ass. Professor,

Department of Mechanical Engineering
Priyadarshini College of Engineering,
Nagpur, Maharashtra, India

Mrunal Ratan Pawar

Student,

Department of Mechanical Engineering
Priyadarshini College of Engineering,
Nagpur, Maharashtra, India

Pritesh Rajesh Meshram

Student,

Department of Mechanical Engineering
Priyadarshini College of Engineering,
Nagpur, Maharashtra, India

Samyak Swapnil Wasnik

Student,

Department of Mechanical Engineering
Priyadarshini College of Engineering,
Nagpur, Maharashtra, India

Shubham Arun Ninawe

Student,

Department of Mechanical Engineering
Priyadarshini College of Engineering,
Nagpur, Maharashtra, India

Tejas Gajanan Bhajbhuj

Student,

Department of Mechanical Engineering
Priyadarshini College of Engineering,
Nagpur, Maharashtra, India

Abstract— The increasing adoption of electric vehicles (EVs) has created a need for reliable, sustainable, and cost-effective charging infrastructure. This project presents the design and development of a Hybrid Solar Tracking, Wind Energy, and AC Mains Based EV Charging Station that combines multiple energy sources to improve charging reliability and renewable energy utilization. The proposed system consists of a 30 W solar panel, 10 W wind turbine, automatic solar tracking mechanism, battery storage, DC-DC boost converter, voltage sensor, Arduino controller, L298 motor driver, LCD display, inverter, and EV charging unit. LDR sensors detect the intensity of sunlight from different directions, and the Arduino controls the motor through the L298 driver to orient the solar panel toward maximum sunlight. The wind turbine provides additional electrical energy during suitable wind conditions. Generated renewable energy is regulated and stored in a rechargeable battery for later use. An optional AC mains supply is incorporated as a backup when renewable generation is insufficient. The stored DC energy can be supplied to the EV charging system and DC loads, while the inverter provides AC power for AC loads. The proposed system aims to improve renewable energy harvesting, reduce grid dependency, provide reliable EV charging, and promote clean and sustainable transportation.

Keywords— Hybrid EV Charging, Solar Tracking, Wind Energy, Battery Storage, Renewable Energy etc.

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has created a significant requirement for efficient, reliable, and sustainable charging infrastructure. EVs are increasingly being adopted because they offer lower operating emissions, reduced dependence on petroleum-based fuels, and the potential to support cleaner transportation. However, the increasing number of EVs also increases the demand for electrical energy. Conventional EV charging stations generally depend on electricity from the utility grid, which may increase the load on the electrical network and indirectly contribute to carbon emissions when the electricity is generated from fossil-fuel-based sources. Therefore, integrating renewable energy sources with EV charging stations is an important approach toward sustainable transportation [1][2].

Solar photovoltaic (PV) energy is one of the most suitable renewable energy sources for EV charging because sunlight is freely available and solar panels can be installed on rooftops, parking structures, and open areas. However, the output of a solar panel varies according to sunlight intensity, weather conditions, and the position of the sun. A fixed solar panel cannot continuously remain perpendicular to sunlight throughout the day, resulting in reduced energy harvesting. To overcome this limitation, the proposed project incorporates an automatic solar tracking mechanism. Light Dependent Resistor (LDR) sensors are used to detect the relative intensity of sunlight. An Arduino microcontroller processes the sensor signals and operates a DC geared motor through an L298 motor driver. The motor changes the orientation of the solar panel toward the direction of higher sunlight intensity, thereby improving solar energy utilization [3][4].

In addition to solar energy, the proposed system incorporates a small wind energy generation unit. A 10 W wind turbine converts available wind energy into electrical energy. Solar and wind resources have complementary characteristics in many operating conditions; therefore, combining them can improve the availability of renewable energy compared with relying on only one source. During periods of adequate sunlight, the solar panel acts as the primary renewable source, while the wind turbine contributes additional energy whenever sufficient wind is available. The generated electrical energy from these sources is regulated and directed toward battery storage through suitable charging and power-conditioning circuits [5].

A rechargeable battery is included as an energy storage unit to store excess renewable energy and supply power when solar or wind generation is temporarily unavailable. A DC-DC boost converter is used to regulate or increase the available DC voltage to a suitable level for the charging system. Proper power conditioning is important because the voltage generated by solar and wind sources can vary according to environmental conditions. The battery therefore provides a stable energy source for the EV charging unit and connected loads [6][7].

To improve the reliability of the charging station, an optional AC mains supply is included as a backup energy source. When renewable energy generation is insufficient or the battery reaches a low state of charge, the mains supply can provide the required power. This hybrid arrangement reduces dependence on a single energy source and helps maintain charging availability. The system can also support both DC and AC loads. DC loads can be powered directly from the battery through regulated circuits, while an inverter converts DC battery power into AC power for suitable AC loads [8][9].

Monitoring and control are important features of the proposed system. A voltage sensor measures the battery or system voltage, while an LCD display provides information such as voltage level, charging condition, and operating status. The Arduino controller coordinates the solar tracking operation and can also be used for basic energy-management functions. A mechanical frame securely supports the solar panel, tracking motor, wind turbine, battery, electronic circuits, and charging components [10].

Overall, the proposed hybrid EV charging station combines solar tracking, wind energy generation, battery storage, power conversion, monitoring, and optional AC mains backup in a single system. The project aims to improve renewable energy utilization, increase charging reliability, reduce grid dependency, and demonstrate a practical approach toward clean and sustainable electric transportation.

II. PROBLEM IDENTIFICATION

- **Dependence on Grid Electricity:** Conventional EV charging stations mainly rely on AC mains, increasing grid load, electricity consumption, and operating costs while limiting renewable energy utilization.
- **Low Solar Energy Harvesting:** Fixed solar panels cannot continuously face the sun, causing reduced energy generation as the solar position changes throughout the day.
- **Intermittent Renewable Sources:** Solar and wind power depend on weather and environmental conditions, creating fluctuations in available energy for EV charging.
- **Limited Energy Storage:** Without suitable battery storage and power-conditioning circuits, excess renewable energy cannot be effectively stored and utilized during low-generation periods.
- **Charging Reliability:** Insufficient renewable generation can interrupt EV charging, particularly during cloudy weather or low-wind conditions.
- **Monitoring Requirements:** Continuous monitoring of voltage, battery condition, power source, and charging status is necessary for safe and efficient system operation.

A. Existing System

Existing EV charging stations primarily depend on electricity supplied by the conventional AC utility grid. Some modern systems incorporate fixed solar photovoltaic panels with battery storage to reduce grid consumption. However, these systems generally operate with a single energy source or limited renewable-energy integration. Solar-based stations can supply EV charging during sufficient sunlight, while grid electricity supports operation during low solar availability. Monitoring and energy-management features may also be

included, but complete integration of solar tracking, wind generation, battery storage, and grid backup is less common.

B. Drawbacks

The existing systems have several limitations, including dependence on grid electricity and reduced renewable-energy utilization. Fixed solar panels cannot continuously align with the sun, resulting in lower energy harvesting throughout the day. Solar generation is also affected by weather and nighttime conditions. Systems relying on a single renewable source may experience interruptions during low generation. Additionally, limited battery storage and basic monitoring can reduce charging reliability, while the absence of integrated wind generation restricts the availability of renewable power during periods of low solar radiation.

III. LITERATURE REVIEWS

A) Literature Survey:

Bhimaraju and Mahesh (2024) reviewed recent developments in photovoltaic (PV) and wind hybrid renewable energy systems. The study examined different system configurations, energy-management methods, optimization techniques, and applications. The authors highlighted that combining solar and wind sources improves renewable energy availability and reduces the limitations associated with individual sources. Battery storage and effective power management were identified as important for maintaining reliable power supply. The review also discussed challenges related to renewable intermittency, system sizing, cost, and optimization. However, practical integration with EV charging stations and low-cost solar tracking mechanisms requires further investigation.

Thirunavukkarasu, Sawle, and Lala (2023) presented a comprehensive review of optimization techniques used for hybrid renewable energy systems. The research analyzed methods for optimal sizing, component selection, energy management, and economic operation of hybrid systems. Different conventional and advanced optimization algorithms were compared based on technical and economic performance. The authors emphasized that optimization can improve system reliability while reducing operating costs and energy losses. The study provides valuable guidance for designing hybrid solar-wind systems. However, hardware-based implementation with automatic solar tracking and EV charging applications remains comparatively less explored.

Basnet, Deschinkel, Le Moyne, and Péra (2023) reviewed standalone and grid-integrated hybrid renewable energy systems with particular emphasis on system optimization and energy-management strategies. The study examined different renewable-source combinations, storage technologies, control methods, and grid-interconnection approaches. The authors reported that intelligent energy management can effectively coordinate renewable generation, battery storage, and loads under variable operating conditions. Hybrid systems can improve reliability and reduce grid dependency. However, practical low-cost systems combining solar tracking, wind generation, battery storage, and EV charging require additional experimental development and validation.

León Gómez, De León Aldaco, and Aguayo Alquicira (2023) investigated hybrid renewable energy system architectures, battery technologies, and optimization techniques. The authors compared different combinations of renewable energy sources and evaluated the role of batteries in maintaining energy availability during renewable fluctuations. Various optimization approaches were discussed for improving system efficiency, reliability, and economic performance. The study demonstrated that appropriate battery selection and system architecture are essential for successful hybrid renewable applications. Nevertheless, integration of simple embedded controllers, automatic solar tracking, and practical EV charging stations was not extensively addressed.

Giedraityte, Rimkevicius, Marciukaitis, Radziukynas, and Bakas (2025) reviewed optimization approaches used in hybrid renewable energy systems and identified major future challenges. The study emphasized the importance of optimal component sizing, energy-management strategies, renewable-resource forecasting, and economic optimization. Combining multiple renewable sources was shown to improve energy reliability and reduce dependence on conventional generation. The authors also highlighted challenges associated with renewable intermittency, storage costs, control complexity, and system scalability. The findings support the development of hybrid solar-wind charging systems, although practical small-scale EV charging prototypes with solar tracking remain an area for further development.

Kechida and co-authors (2024) developed a smart control and management approach for a standalone hybrid renewable energy system. The research focused on coordinating renewable sources, energy storage, and electrical loads to achieve stable and reliable operation. Intelligent control techniques were used to improve energy utilization under changing renewable generation conditions. The study demonstrated that effective energy management can minimize power fluctuations and improve system performance. Battery storage was important for maintaining supply during low renewable generation. However, the proposed approach primarily addressed standalone energy systems rather than a compact EV charging station incorporating LDR-based solar tracking and AC mains backup.

Nassar, Alsadi, El-Khozondar, Ismail, Al-Maghalseh, Khatib, and co-authors (2022) designed and analyzed an isolated hybrid renewable energy system through a practical case study. The research considered renewable resource availability, system configuration, energy storage, and load requirements to achieve reliable electricity generation. The study demonstrated the usefulness of combining renewable sources and battery storage for isolated applications where grid access is limited. Proper system sizing was found to be essential for maintaining energy reliability and minimizing costs. However, the research did not specifically concentrate on automatic solar tracking or renewable-powered EV charging infrastructure.

Rasool, Abbasoglu, and Hashemipour (2022) analyzed and optimized a hybrid wind and solar photovoltaic generation system for an off-grid small village. The research investigated the complementary characteristics of solar and wind resources to improve electricity availability. Optimization was used to determine suitable system configurations and improve overall performance for rural applications. The results demonstrated

that hybrid renewable generation can provide more reliable power than using a single renewable source. The study also emphasized the importance of considering local renewable-resource conditions. However, EV charging, solar tracking, and real-time embedded monitoring were outside the main scope.

Hossen, Islam, Ishraque, Shezan, and Arifuzzaman (2022) designed and evaluated a hybrid solar-wind-biomass renewable energy system while considering meteorological conditions. The study investigated how variations in solar radiation, wind speed, and other environmental factors influence renewable power generation. The integration of multiple renewable sources improved energy availability and reduced dependence on a single generation technology. The research also evaluated power-system performance under different operating conditions. The findings demonstrate the importance of weather information when designing hybrid systems. However, the system included biomass rather than focusing specifically on EV charging, solar tracking, and AC mains-supported operation.

Bansal (2022) reviewed sizing and forecasting techniques for photovoltaic-wind hybrid renewable energy systems. The study analyzed methods for determining appropriate capacities of solar panels, wind turbines, batteries, and other system components according to energy demand and renewable-resource availability. Forecasting techniques were identified as important for managing the variability of solar and wind generation. The research showed that accurate sizing and prediction can improve system reliability, reduce excess energy, and lower overall costs. However, most reviewed approaches were focused on system-level planning and optimization, leaving scope for practical EV charging prototypes with automatic solar tracking and real-time monitoring.

B) Literature Summary

- Recent studies show that hybrid solar-wind systems improve renewable energy availability and reliability compared with single-source systems.
- Battery energy storage is widely used to manage fluctuations and provide continuous power during low renewable generation.
- Researchers have emphasized optimization and energy-management techniques for improving system sizing, efficiency, and economic performance.
- Several studies investigate standalone and grid-integrated architectures for reliable renewable power supply.
- Advanced control and forecasting methods help manage variable solar radiation and wind conditions.
- However, most research focuses on simulation, optimization, and large-scale systems, with limited practical implementation of low-cost solar tracking, EV charging, and AC mains backup.

C) Research Gap

- Most existing hybrid systems use fixed solar panels, with limited implementation of LDR-based automatic solar tracking for improved energy harvesting.
- Practical integration of solar, wind, battery storage, and AC mains backup within a compact EV charging system remains limited.

- Many studies emphasize simulation and optimization, while low-cost Arduino-based experimental prototypes require further development.
- Real-time monitoring of voltage, battery condition, charging status, and energy source selection is not consistently incorporated.
- Existing research often targets large-scale applications rather than small, economical EV charging systems.
- Therefore, a practical system integrating solar tracking, wind generation, battery storage, monitoring, AC backup, and EV charging can address these limitations.

IV. RESEARCH METHODOLOGY

A) Proposed System

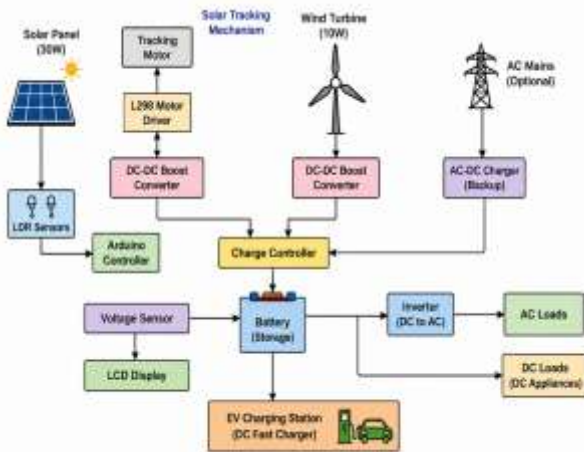


Figure 1. Proposed System

- The 30 W solar panel captures solar energy, while LDR sensors detect the direction of maximum sunlight to improve energy generation throughout the day.
- The Arduino controller processes the LDR sensor signals and controls the L298 motor driver, which rotates the DC geared motor to automatically align the solar panel with the sun.
- Simultaneously, the 10 W wind turbine converts wind energy into electrical energy whenever sufficient wind is available, providing an additional renewable power source.
- The electrical output from both the solar panel and wind generator is regulated using DC-DC boost converters to obtain a stable DC voltage.
- The regulated power is supplied to a battery charging circuit, which safely charges the rechargeable battery and stores energy for continuous operation.
- When renewable energy is insufficient, the optional AC mains supply automatically acts as a backup source to maintain uninterrupted battery charging and EV charging.
- A voltage sensor continuously monitors battery voltage and system status, while the 16×2 LCD display shows real-time voltage, charging status, and active power source.
- The stored battery energy powers the EV charging station, supplies DC loads directly, and, through an inverter, provides AC power for household or industrial AC loads, ensuring reliable and efficient hybrid energy utilization.

B) Hardware Used

- Arduino UNO: Acts as the main controller, processing LDR signals and managing the solar tracking operation.
- 30 W Solar Panel: Converts sunlight into electrical energy for battery charging and EV charging.

- 10 W Wind Turbine: Generates additional electrical energy from available wind.
- LDR Sensors: Detect sunlight intensity from different directions for automatic panel positioning.
- L298 Motor Driver: Controls the direction and speed of the tracking motor according to Arduino signals.
- DC Geared Motor: Mechanically rotates the solar panel toward the direction of maximum sunlight.
- DC-DC Boost Converter: Regulates and increases the generated DC voltage to the required level.
- Rechargeable Battery: Stores renewable energy and supplies power when generation is insufficient.
- Voltage Sensor: Measures battery/system voltage for monitoring and control.
- 16×2 LCD: Displays voltage, charging status, and operating conditions.
- Inverter: Converts battery DC into AC for AC loads.
- EV Charging Unit: Provides regulated electrical power for charging the electric vehicle.

V. CALCULATION

1. Solar Power Generation

Given:

- Solar panel rating = 30 W
- Operating voltage ≈ 12 V

Solar current:

$$I_s = \frac{P_s}{V_s}$$

$$I_s = \frac{30}{12} = 2.5A$$

Therefore, the solar panel can provide approximately 2.5 A at rated conditions.

2. Wind Power Generation

Given:

- Wind generator rating = 10 W
- Output voltage ≈ 12 V

Wind generator current:

$$I_w = \frac{P_w}{V_w}$$

$$I_w = \frac{10}{12} = 0.83A$$

Therefore, the wind generator can provide approximately 0.83 A at rated conditions.

3. Total Renewable Power

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

$$P_{total} = 30 + 10 = 40W$$

Thus, the theoretical maximum renewable generation is approximately 40 W.

4. Battery Energy Storage

Assuming a 12 V, 7 Ah battery:

$$E = V \times Ah$$

$$E = 12 \times 7 = 84Wh$$

Therefore, the battery has approximately 84 Wh of nominal stored energy.

5. Approximate Battery Charging Time

Assuming the full 40 W renewable power is available and ignoring losses:

$$t = \frac{E}{P}$$

$$t = \frac{84}{40} = 2.1 \text{ hours}$$

Considering converter, wiring, charging, and environmental losses, the practical charging time will be higher than 2.1 hours.

6. Boost Converter Output

If the renewable source provides 12 V, 3 A and the boost converter produces 24 V, assuming 90% efficiency:

$$P_{out} = 12 \times 3 \times 0.9$$

$$P_{out} = 32.4W$$

Output current:

$$I_{out} = \frac{32.4}{24} = 1.35A$$

7. Inverter Output

If the battery supplies 84 Wh and the inverter efficiency is assumed to be 85%:

$$E_{AC} = 84 \times 0.85$$

$$E_{AC} = 71.4Wh$$

Therefore, approximately 71.4 Wh of usable AC energy can be obtained from the battery through the inverter.

8. EV Charging Energy

If the prototype EV charging load is assumed to be 40 W:

$$t = \frac{84}{40}$$

$$t = 2.1 \text{ hours}$$

Considering system losses, the actual charging duration will depend on battery condition, converter efficiency, renewable generation, and EV charging requirements.

VI. ADVANTAGES AND APPLICATIONS

A) Advantages

- Renewable Energy: Utilizes clean solar and wind energy, reducing dependence on conventional electricity.
- Solar Tracking: LDR-based tracking improves solar energy collection by maintaining better panel orientation.
- Hybrid Operation: Combines solar, wind, battery, and optional AC mains for improved reliability.
- Energy Storage: Battery stores excess renewable energy for later use.
- Real-Time Monitoring: Voltage sensor and LCD provide simple system-status monitoring.
- Eco-Friendly: Supports sustainable EV charging and reduces environmental impact.

B) Applications

- EV Charging: Suitable for small-scale electric vehicle charging stations and demonstration prototypes.
- Residential Charging: Can support EV charging and auxiliary household loads.
- Educational Institutions: Useful for demonstrating solar tracking, wind generation, and hybrid energy systems.

- Parking Areas: Can provide renewable charging facilities in parking locations.
- Remote Areas: Suitable for locations with limited grid availability.
- Renewable Laboratories: Useful for research, testing, and practical demonstrations of hybrid renewable-energy technologies.

VII. RESULTS ANALYSIS

Results Analysis Based on Time Duration :

For the proposed 30 W solar + 10 W wind hybrid system, the following table can be used to represent the expected power variation from 6:00 AM to 6:00 PM. These are illustrative/expected prototype values, not measured experimental readings. Actual output will depend on sunlight, weather, panel orientation, and wind speed.

Time	Solar Power (W)	Wind Power (W)	Total Renewable Power (W)
6:00 AM	0	2	2
7:00 AM	5	3	8
8:00 AM	10	4	14
9:00 AM	16	5	21
10:00 AM	22	6	28
11:00 AM	27	7	34
12:00 PM	30	8	38
1:00 PM	29	7	36
2:00 PM	27	6	33
3:00 PM	23	5	28
4:00 PM	17	4	21
5:00 PM	9	3	12
6:00 PM	2	2	4

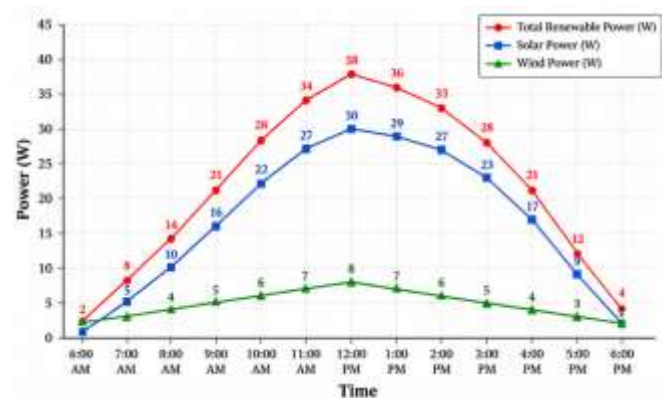


Figure 2. Daily Solar, Wind and Total Renewable Power Variation

The graph shows renewable power variation from 6:00 AM to 6:00 PM. Solar generation peaks at noon, wind contributes continuously, and combined renewable power reaches 38 W.

The results indicate that renewable power gradually increases from the morning as solar radiation increases. The maximum combined renewable power is approximately 38 W around 12:00 PM, consisting of 30 W solar and 8 W wind generation. After noon, solar output gradually decreases as solar irradiance reduces. The wind generator provides

supplementary power throughout the period, helping compensate for variations in solar generation. The hybrid system therefore provides better energy availability than relying only on the solar panel.

Note: Since the system is rated at 30 W solar + 10 W wind = 40 W maximum, the table keeps the combined output below 40 W. For your final report, these values should be replaced with actual voltage and current measurements if you have recorded them.

VIII. CONCLUSION

The proposed Hybrid Solar Tracking, Wind Energy, and AC Mains Based EV Charging Station provides a sustainable and reliable approach for renewable-energy-powered electric vehicle charging. The system combines a 30 W solar panel with an LDR-based automatic tracking mechanism, enabling the panel to follow the direction of maximum sunlight and improve energy harvesting. A 10 W wind turbine provides additional renewable power during suitable wind conditions. The generated energy is regulated using a DC-DC boost converter and stored in a rechargeable battery for later use. An optional AC mains supply provides backup power whenever renewable generation is insufficient. The Arduino controller, L298 motor driver, voltage sensor, and LCD display enable automatic tracking, monitoring, and basic system control. The stored battery energy can supply the EV charging unit and DC loads, while an inverter supports AC loads. Overall, the proposed system demonstrates the feasibility of integrating multiple renewable sources with energy storage and backup supply, reducing dependence on conventional electricity and supporting cleaner transportation. The prototype can serve as a foundation for developing larger and more efficient renewable-powered EV charging stations.

IX. FUTURE SCOPE

- Higher Capacity: Use higher-rated solar panels, wind turbines, and batteries for practical EV charging.
- Advanced Tracking: Implement dual-axis tracking and MPPT for improved solar energy harvesting.
- IoT Monitoring: Add Wi-Fi/IoT for remote monitoring, data logging, and smart energy management.
- Smart Charging: Develop automatic renewable/grid source selection based on battery SOC and charging demand.

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