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A Hybrid PV–Wind Energy System for Autonomous Electric Vehicle Charging

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***ABSTRACT*:** This research paper presents the design and implementation of an automatic Electric Vehicle (EV) charging system powered by a hybrid combination of solar and wind energy sources. The proposed system integrates a gearless Permanent Magnet Generator (PMG), thin-film photovoltaic panels, and a Maximum Power Point Tracking (MPPT) controller to enhance energy conversion efficiency.

The hybrid configuration ensures continuous power availability, improves battery safety, and supports sustainable transportation. Additionally, the study discusses system design considerations, power flow control strategies, and efficiency analysis. Recommendations for future large-scale deployment and technological improvements are also presented.

KEYWORDS:

Battery, Solar Panels, Mini Wind Turbine**,** (PMG), MPPT Controller, Dump Load, Sensors and Controllers

1. INTRODUCTION

In recent years, the global automotive sector has undergone a significant transformation from conventional internal combustion engine (ICE) vehicles to Electric Vehicles (EVs). This transition is primarily driven by the urgent need to reduce carbon emissions, mitigate climate change, and promote sustainable transportation. EVs offer several environmental benefits, including zero tailpipe emissions, reduced air pollution, and decreased dependence on fossil fuels.

However, one of the major challenges in the widespread adoption of electric vehicles is the development of efficient and sustainable charging infrastructure. Conventional EV charging systems rely heavily on electricity supplied from the national grid, which is often generated using non-renewable energy sources such as coal and natural gas. This dependence reduces the environmental benefits of

EVs and increases operational costs. Additionally, grid-based charging requires the vehicle to remain stationary, limiting mobility and convenience.

To overcome these limitations, this paper proposes a Hybrid Renewable Energy System (HRES) for automatic charging of electric vehicles. The system integrates solar and wind energy sources to enable continuous energy generation during both stationary and moving conditions. Solar panels mounted on the vehicle surface capture sunlight, while a compact wind turbine generates electrical energy from airflow during motion.

The generated energy from both sources is regulated using a Maximum Power Point Tracking (MPPT) controller to ensure maximum efficiency. A gearless Permanent Magnet Generator (PMG) is used in the wind subsystem for efficient energy conversion with minimal losses. The system also incorporates intelligent control mechanisms to manage power flow and maintain battery safety.

The proposed hybrid system reduces dependence on conventional energy sources, enhances vehicle range, and supports sustainable mobility. It represents a significant step toward the development of autonomous and eco-friendly EV charging technologies.

2. LITERATURE SURVEY

2.1. Vehicle-Integrated Photovoltaics (VIPV)

Vehicle-Integrated Photovoltaic systems have evolved from experimental concepts to practical implementations. Studies show that solar panels mounted on vehicles can significantly extend driving range, especially in lightweight EVs.
Manufacturers such as Aptera and Nissan have demonstrated that VIPV systems can provide substantial annual range improvements. However, efficiency depends on solar availability and vehicle design.

2.2. On-Vehicle Wind Energy Harvesting (Micro-Turbines)

Studies on vehicle-mounted micro-turbines reveal both opportunities and limitations. Although the power available from airflow increases with the cube of vehicle speed, the amount of energy that can be harvested is constrained by turbine size, placement, and the resulting aerodynamic drag. Experimental and computational analyses show that poorly positioned turbines can increase drag, offsetting their energy gains. However, recent investigations (2024–2025) demonstrate that optimized turbine housings, gearless Permanent Magnet Generator (PMG) configurations, and low-profile designs can improve efficiency while minimizing drag penalties. Despite these advancements, real-world demonstrations remain limited and require further validation across different vehicle types and environments.

2.3. Power Electronics and MPPT for Hybrid PV–Wind Systems

Maximum Power Point Tracking (MPPT) is crucial for extracting optimal energy from variable solar and wind inputs. Conventional algorithms such as Perturb-and-Observe (P&O) and Incremental Conductance (INC) are widely used due to their simplicity and robustness, whereas advanced adaptive and AI-based techniques offer improved tracking under rapidly changing environmental conditions. In hybrid PV–wind systems, controllers must simultaneously manage two distinct and fluctuating inputs. Recent studies recommend hierarchical or dual-loop MPPT architectures, along with robust DC–DC converter topologies, to ensure reliable operation and enhance battery health.

2.4. Gearless Permanent Magnet Generators (PMG) and Small-Scale Generators

Gearless PMGs are commonly adopted for low-maintenance, small-scale wind systems because they reduce mechanical losses, noise, and maintenance frequency. Several design studies have optimized stator and rotor configurations to minimize cogging torque and improve efficiency at low wind speeds—key attributes for on-vehicle turbines. These generators integrate effectively with rectifiers and MPPT-based DC front-end circuits for direct battery charging applications.

2.5. System-Level Studies and Field Demonstrations

Integrated hybrid systems that combine PV, wind, energy storage, and intelligent control have shown substantial improvements in uptime and reliability at both station and vehicle scales. Field tests confirm that Vehicle-Integrated Photovoltaic (VIPV) installations are mature enough for real-world implementation, particularly for commercial fleets and delivery vehicles where predictable duty cycles and available surface area enhance benefits. Industry prototypes from manufacturers such as Aptera and Nissan highlight growing commercial interest and technological feasibility for full-scale integration of renewable energy systems into modern EVs.

2.6. Identified Gaps and Research Opportunities

- Energy vs. Drag Quantification: Most turbine studies lack comprehensive driving-cycle analyses that balance harvested energy against additional aerodynamic drag. Further computational fluid dynamics (CFD) and on-road testing are required.
- Compact Hybrid MPPT Hardware: Few low-cost, dual-input MPPT modules specifically designed for vehicular integration exist, presenting opportunities for hardware prototyping and cost optimization.
- Long-Term Field Trials: Limited longitudinal data are available regarding battery degradation, maintenance cycles, and lifecycle carbon impact for combined PV–wind systems.
- Aerodynamic Integration: Future research should emphasize turbine and solar array integration

techniques that minimize drag and weight, including deployable or conformal surface designs.

2.7. How This Project Addresses Identified Gaps

- Aerodynamic-First Design: The proposed project prioritizes CFD-based turbine placement and conformal photovoltaic integration to address the energy-drag optimization challenge.
- Prototype Hybrid MPPT Controller: A compact dual-input MPPT system with a dump-load feature is proposed to enhance real-world applicability.
- Field Validation Plan: The design includes structured testing under various driving cycles, energy audits, and battery health monitoring, addressing the lack of long-term field performance data.

2.8. Practical Design Recommendations

- Utilize flexible thin-film or deployable PV panels to maximize energy capture without adding excessive weight.
- Employ a gearless PMG in the micro-turbine subsystem to ensure efficient energy conversion and minimal mechanical losses.
- Implement a dual-input MPPT architecture with an energy buffer (supercapacitor or small Li-ion cell) to stabilize transient power fluctuations and protect the main battery.
- Conduct pilot studies on low-drag, low-energy vehicles or delivery fleets where VIPV technology yields maximum benefits.

3. EXISTING SYSTEM

Conventional Electric Vehicle (EV) charging systems primarily depend on grid-based electricity or standalone renewable energy sources such as solar or wind power. Most traditional EV charging infrastructures operate through plug-in stations connected to the national grid, where the supplied electricity is often generated from non-renewable sources like coal and natural gas. This dependency not only increases grid load and operational costs but also indirectly contributes to carbon emissions, thereby diminishing the environmental advantages of electric mobility. Moreover, grid-based charging restricts vehicle mobility, as the vehicle must remain stationary during the charging process.

To address these limitations, several research initiatives and prototype models have explored the integration of renewable energy technologies into EV charging systems. Vehicle-Integrated Photovoltaic (VIPV) solutions—implemented by manufacturers such as Aptera, Lightyear, and Nissan—employ solar panels mounted on the vehicle body to provide supplemental charging.

These systems can extend the vehicle's driving range and reduce reliance on external charging networks. However, solar-only configurations face performance constraints during night-time and low-sunlight conditions, making them insufficient as a standalone energy source for continuous charging.

4. PROPOSED SYSTEM

The proposed system introduces a hybrid renewable energy–based automatic charging mechanism for electric vehicles that integrates both solar and wind energy sources to achieve continuous, efficient, and eco-friendly charging. This configuration is designed to overcome the limitations of conventional single-source charging systems by utilizing complementary renewable inputs—solar panels generate power during daylight hours, while a compact wind turbine produces electricity when the vehicle is in motion or when sufficient wind is available.

The energy harvested from both sources is regulated through a Maximum Power Point Tracking (MPPT) hybrid charge controller, which independently optimizes the power flow from each source to ensure maximum energy extraction under varying environmental conditions. The MPPT controller further manages power distribution among three key pathways: charging the vehicle's battery, supplying the operational load, and diverting excess power to a dump load to prevent overcharging.

At the core of the system, a gearless Permanent Magnet Generator (PMG) is connected to the wind turbine, enabling efficient conversion of mechanical wind energy into electrical power with minimal losses and maintenance. Simultaneously, thin-film solar panels mounted on the vehicle's surface convert sunlight into direct current (DC) power, maintaining reliable performance even under partially shaded or diffuse light conditions.

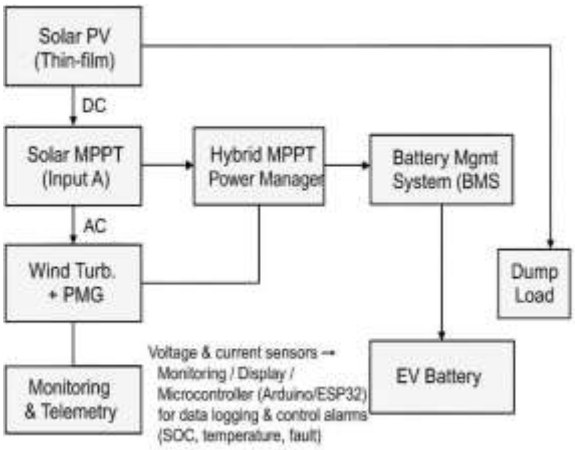

Fig. 1. Block Diagram for Automatic Charging of Electric Vehicle Using Hybrid Solar–Wind System The block diagram illustrates the

architecture of the proposed hybrid renewable energy–based
automatic charging system for electric vehicles. Both solar and wind energy sources are integrated into a unified hybrid power management unit,
where intelligent control algorithms regulate energy flow and continuously monitor key system parameters such as voltage, current, and the battery's State of Charge (SOC). The harvested energy is efficiently stored and
utilized to charge the vehicle's battery automatically, eliminating the need for manual intervention and enabling a self-sustaining charging mechanism.

The hybrid configuration enhances system reliability by ensuring uninterrupted energy availability, as one renewable source can compensate when the other is insufficient. This significantly reduces dependence on external charging infrastructure and promotes sustainable mobility through the exclusive use of clean energy sources.
Furthermore, the integration of a Maximum Power Point Tracking (MPPT) controller improves overall system efficiency by approximately 20–30% compared to conventional control techniques. The dual-source configuration also contributes to improved system uptime and prolonged battery lifespan by maintaining balanced energy input and optimal charging conditions.

Additionally, the proposed system is modular, scalable, and adaptable, making it suitable for a wide range of electric vehicles, including two-wheelers, passenger cars, and lightweight commercial vehicles. By combining renewable energy generation with intelligent energy management, the system represents a significant advancement toward autonomous, efficient, and environmentally sustainable EV charging.

5. MODIFIED MODEL ARCHITECTURE

The modified model architecture presents an improved hybrid energy-based charging system that integrates solar photovoltaic (PV) panels and a wind turbine with a centralized power management unit. The system incorporates a hybrid Maximum Power Point Tracking (MPPT) controller to optimize energy extraction from both sources under varying environmental conditions. A Battery Management System (BMS) ensures safe and efficient charging by monitoring key parameters such as voltage, current, and State of Charge (SOC).

Additionally, the architecture includes a dump load mechanism to handle excess energy and prevent overcharging, along with a monitoring and telemetry unit for real-time data acquisition and system control. This enhanced design improves system efficiency, reliability, and adaptability for various electric vehicle applications.

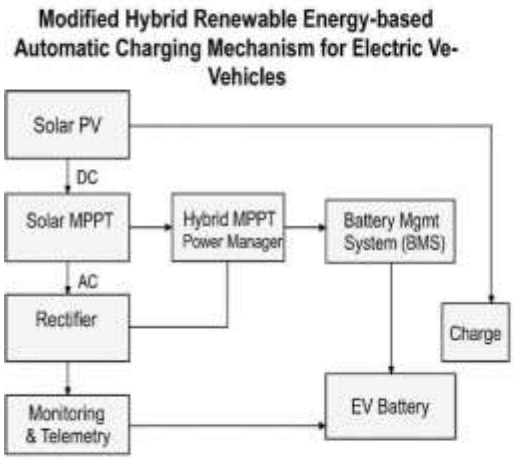

Fig.2. Architecture for Automatic Charging of Electric Vehicle Using Hybrid Solar–Wind System

6. CONCLUSION

The proposed Hybrid Renewable System for Automatic Charging of Electric Vehicles (EVs) presents an innovative, sustainable, and self-**sufficient** solution to reduce dependency on conventional grid-based charging infrastructure. By integrating both solar photovoltaic (PV) and wind energy sources into a unified hybrid configuration, the system ensures continuous and reliable energy generation under varying environmental conditions

The incorporation of a Maximum Power Point Tracking (MPPT) controller enables optimal energy extraction from each renewable source independently. The hybrid power management unit efficiently distributes the harvested energy to the Battery Management System (BMS), ensuring safe, balanced, and intelligent charging. This significantly minimizes power losses, enhances battery lifespan, and improves overall system performance.

The use of a gearless Permanent Magnet Generator (PMG) in the wind subsystem ensures high efficiency with reduced maintenance requirements. Additionally, the inclusion of a dump load mechanism prevents overcharging and enhances operational safety. The integration of microcontroller-based monitoring systems, such as Arduino or ESP32, enables real-time tracking of voltage, current, State of Charge (SOC), and fault conditions, making the system intelligent and adaptive

Compared to conventional grid-dependent or single-source renewable systems, the proposed hybrid system demonstrates improved reliability, higher energy utilization, and reduced environmental impact. This work highlights the potential of combining solar and wind energy to develop autonomous and eco-friendly EV charging solutions.

Future advancements may focus on aerodynamic optimization, lightweight solar integration, and the application of Artificial Intelligence (AI) for adaptive MPPT control and predictive maintenance. Overall, the system contributes significantly toward sustainable transportation and next-generation EV charging technologies.

7. FUTURE SCOPE

The proposed hybrid renewable system provides a strong foundation for developing self-sustaining EV charging solutions; however, several opportunities exist for further enhancement and large-scale implementation.

Future work can focus on integrating advanced energy storage technologies such as Lithium Iron Phosphate ($LiFePO_4$) batteries, solid-state batteries, and supercapacitors to improve efficiency, safety, and lifespan. The adoption of lightweight, flexible, and high-efficiency solar panels can further enhance power generation while maintaining vehicle aerodynamics.

The integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies offers significant potential for intelligent energy management. AI-based MPPT algorithms can dynamically optimize power extraction under varying conditions, while IoT-enabled systems can support real-time monitoring, predictive maintenance, and cloud-based data analysis.

Additionally, future research may explore improved aerodynamic designs for wind turbines, scalable system architectures, and cost-effective hardware solutions for widespread adoption. These advancements will help achieve higher efficiency, improved reliability, and complete energy autonomy in EV charging systems.

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