

Smart EV Charging Station Utilizing Hybrid Power Generation System for Sustainable Transportation: A Review

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Abstract –

Electric vehicle (EV) adoption has been increasing at a fast pace which creates a need for charging systems that provide sustainable energy sources and dependable service and operational efficiency. Fossil fuel-based energy sources continue to power conventional grid-based EV charging stations which results in indirect carbon emissions and increased grid pressure during peak operational times. The project demonstrates a smart electric vehicle charging station which operates using a combined solar and wind energy system for sustainable transportation activities. The system uses solar photovoltaic panels together with a wind energy generator system that includes dual battery storage for maintaining continuous power supply during different weather situations. A DC–DC boost converter maintains constant voltage levels while the inverter module delivers both AC and DC charging solutions which fulfill different EV charging needs. The Arduino-based power control system utilizes voltage and current sensors along with an LCD display for real-time monitoring of power flow and battery status and load conditions. The intelligent energy management algorithm uses renewable energy sources as the main power source while shifting to grid electricity only after all renewable batteries have been used. The system achieves stable DC bus voltage while balancing energy distribution and enhancing charging performance according to simulation results and practical tests. The proposed hybrid renewable charging station provides an economical and environmentally sustainable solution which meets the requirements of future electric vehicle charging systems.

Keywords: *Electric Vehicle Charging Station, Hybrid Solar–Wind Energy System, Renewable Energy Integration, Energy Management System, Sustainable Transportation etc.*

I. INTRODUCTION

Electric vehicles (EVs) are becoming more common in the worldwide transportation industry because people want to solve climate change problems while dealing with high fuel costs and the decline of fossil fuel supplies. The shift towards electric mobility solutions as a cleaner sustainable option has gained momentum from governments and industries and consumers who see it as better than traditional internal combustion engine vehicles. Electric vehicles (EVs) decrease emissions at their exhaust pipes, but their environmental effect depends on the electricity source used to charge their batteries. The emissions produced from fossil fuel power plants that supply power to EV charging stations create a significant environmental impact which diminishes the environmental advantages of electric transportation.

The current state of electric vehicle (EV) charging infrastructure shows that most stations connect to the power grid while power generation throughout the world still relies on coal and oil and natural gas. The growing number of electric vehicles (EVs) causes more people to charge their vehicles at the same time, which creates extra pressure on the power grid, resulting in voltage problems and power supply issues and increasing operating expenses. The process of establishing grid power systems to remote highways and rural areas and developing new territories proves to be both costly and slow. The existing problems demonstrate that society needs to develop new charging systems which need to provide clean energy and operate independently from traditional power systems.

The use of renewable energy to power EV charging stations creates an effective solution for the existing problems. Solar and wind energy sources stand out as the most accessible and eco-friendly options among all renewable energy sources. The sun provides solar energy during the day while wind energy remains accessible at all times because it works together with solar energy production. Hybrid solar-wind systems deliver better system performance because they provide continuous energy output which operates at higher reliability than single-source renewable systems. The hybrid system establishes a constant electricity supply for EV charging needs by eliminating the downtime which occurs with separate renewable power systems.

Renewable-powered charging stations depend on battery energy storage systems to store surplus electricity which they generate during optimal weather conditions and use to supply power during times of low renewable output or high EV charging traffic. The correct management of batteries guarantees stable voltage maintenance while stopping both overcharging and deep discharge incidents to extend the total battery lifespan. The system achieves effective voltage control through power electronic converters which include DC-DC boost converters and inverters which enable the operation of both DC fast charging and AC charging functions.

The operation of contemporary electric vehicle charging systems depends on two essential components which are smart control systems and energy management systems. The system uses microcontroller technology to monitor voltage and current and power and battery status in real time. Intelligent algorithms can prioritize renewable energy usage, optimize charging schedules, and minimize grid dependency during peak demand periods. Smart charging methods bring two advantages because they enhance system performance and help power grids operate efficiently while decreasing operational expenses.

Off-board fast charging stations are increasingly preferred over onboard chargers, as they allow higher charging power without increasing vehicle cost or weight. Fast charging operations require power conversion systems which operate at high capacity and need energy management systems that function effectively to maintain safety and reliable operations. The combination of renewable

energy sources with off-board charging systems results in decreased carbon emissions from fast charging operations while it promotes the establishment of environmentally friendly transportation systems.

The project creates a smart EV charging solution which uses a hybrid solar and wind energy system to power its operations. The proposed system incorporates solar photovoltaic panels, a wind generator, dual battery storage, power electronic converters, and an Arduino-based controller with voltage and current sensors and an LCD display. The system provides flexibility through its ability to deliver both AC and DC charging outputs which meet different electric vehicle charging needs. The centralized energy management algorithm monitors battery conditions and available renewable energy sources, which enables grid power usage when all renewable resources have been used up.

The hybrid renewable electric vehicle charging station provides a practical solution which meets future needs because it solves major problems that include grid dependency and renewable energy fluctuations and peak load demands and power quality problems. The project advances sustainable charging infrastructure development because it enables electric vehicle adoption while promoting environmentally friendly transportation systems.

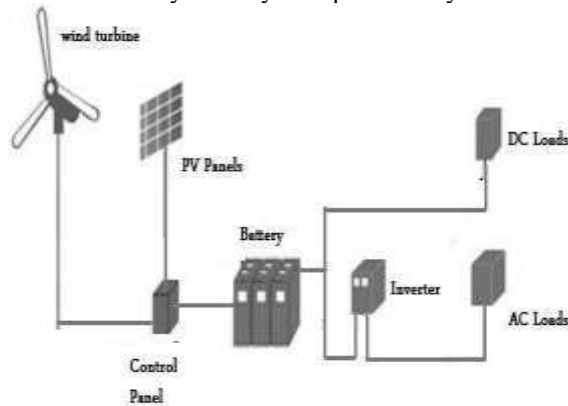


Fig.1. Hybrid Power Generation system

Using hybrid power systems at electric vehicle charging stations provides a dependable and affordable solution for charging needs which can operate beyond standard electrical grid systems into distant areas. The growing use of electric vehicles will depend on hybrid-powered charging stations to develop an environmentally friendly transportation system.

II.

BEHIND RESEARCH

The system for fast charging electric vehicles in indoor spaces operates as a board system but its functionality is restricted because the required electronic components for electricity conversion add to the total electric vehicle expenses. The built-in chargers of electric vehicles fail to provide fast charging capabilities because the expense of electric vehicle electronics and the need to boost vehicle charging capacity create financial barriers.

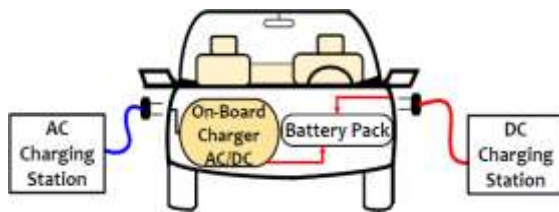


Fig.2. Hybrid EV Charging Station

External chargers use high direct current for electric vehicle charging because it enables faster charging. The external chargers accomplish their AC to DC conversion through dedicated inverters which perform the complete conversion process. The charging process of the car requires higher converter power because it needs faster charging capabilities. The design and development of dependable electric vehicle charging systems at charging stations used findings from multiple published studies.

Hybrid Power :

A hybrid power tool combines two energy sources to supply electricity efficiently. The system operates as a power generation system which uses multiple power sources to deliver reliable power at efficient performance with low emissions while keeping operational expenses to a minimum. The proposed system uses solar and wind energy to produce electrical power. The renewable sources provide substantial benefits when compared to traditional power systems because they deliver an environmentally friendly and affordable permanent energy solution.

The system needs only a small financial investment because it can be set up anywhere without needing specific site requirements. The hybrid system achieves continuous energy production through its use of solar and wind power which makes it suitable for different types of operations. The proposed gadget uses solar and wind power to generate electrical energy. Sunlight and wind power offer greater benefits than all other alternative electricity generation methods. All power assets need to exist in every location. The user wants to pay less than the established fee. The device installation process does not require any specific location selection.

Solar Power :

Solar energy exists as a power source which harnesses the sun's continuous and permanent radiation that reaches Earth. The system provides free energy which produces no emissions and requires only minimal maintenance while offering affordable costs. The system experiences challenges in generating electricity during inclement weather conditions. Solar energy systems operate at higher efficiency levels than traditional energy sources because they need initial funding but deliver power for extended periods while creating fewer emissions.

Wind Power :

Wind power is produced through windmills which serve as sustainable energy systems that require low expenses for both production and maintenance. Wind energy provides power throughout the entire day while producing minimal environmental pollutants. The starting cost is cheaper than for solar energy, and the amount of power produced is determined by the direction of the air flow.

The recommended Hybrid Energy System mixes solar and wind power to solve the short-term nature of individual renewable energy sources. This system provides ongoing power generation which enhances system reliability while it addresses the limitations present in single power sources. The system provides a dependable economical solution which delivers continuous power to remote locations because it reduces gearbox expenses and maintains low emissions.

III.

LITERATURE SURVEY

Brown and Miller (2023) investigated centralized energy management for EV charging networks in Electric Power Systems Research. Their study proposed a centralized control framework for multiple charging stations connected to renewable energy sources. The system enabled load leveling, reduced grid stress, and improved renewable energy utilization. Simulation results showed enhanced overall network efficiency and stability. The authors concluded that centralized energy management is essential for future large-scale EV charging networks, especially with increasing renewable penetration.

Abodwair et al. (2024) conducted a feasibility study of hybrid renewable energy-based EV charging stations. Their research evaluated economic, technical, and environmental aspects of integrating solar and wind systems. Simulation results demonstrated that hybrid systems significantly reduce operational costs and greenhouse gas emissions compared to conventional grid-based charging. The study also highlighted the importance of optimized system sizing and energy management for maximizing efficiency. The authors concluded that hybrid renewable charging stations are both economically viable and environmentally sustainable, making them suitable for deployment in regions with high renewable energy potential.

Sharma and Gupta (2023) proposed a hybrid solar–wind powered EV charging system focusing on voltage regulation and system stability. Their design incorporated DC–DC converters and battery storage to maintain a constant output voltage. The system was tested under varying environmental conditions, and results showed improved efficiency and reliability compared to standalone renewable systems. The authors emphasized that combining solar and wind energy helps reduce intermittency issues and ensures continuous power supply. Their findings support the use of hybrid systems for efficient and reliable EV charging infrastructure.

Singh and Verma (2023) presented a design and simulation of a solar–wind hybrid EV charging system. Their work focused on integrating renewable sources with energy storage and control strategies to manage power fluctuations. Simulation results indicated stable DC bus voltage and efficient energy utilization. The study highlighted that hybrid renewable systems can significantly reduce grid dependency and improve charging reliability. The authors concluded that proper control and energy management are essential for optimizing the performance of renewable-based EV charging stations.

Reddy and Rao (2019) investigated wireless EV charging using a hybrid solar PV and wind energy system. The study integrated renewable energy with wireless power transfer technology to enhance user convenience and flexibility. Experimental results showed efficient energy transfer and reduced dependence on conventional charging methods. The authors emphasized that renewable-powered wireless charging can simplify infrastructure and improve system efficiency. The study concluded that combining wireless charging with hybrid renewable sources offers a promising approach for future EV charging technologies.

Patel and Mehta (2022) developed a hybrid renewable EV charging station using solar and wind energy. Their system included battery storage and power electronic converters to ensure stable power output. The findings demonstrated improved energy management and reliable charging under varying weather conditions. The authors highlighted that hybrid systems reduce carbon emissions and operational costs. The study concluded that renewable-based EV charging stations are an effective solution for sustainable transportation and energy efficiency.

Kumar and Sharma (2025) proposed a smart EV charging station powered by solar and wind energy with integrated IoT monitoring. The system enabled real-time tracking of voltage, current, and battery status. Results showed improved system reliability, efficient energy utilization, and enhanced fault detection. The authors concluded that combining renewable energy with smart monitoring technologies significantly improves the performance and user experience of EV charging systems.

Khan and Ali (2025) presented a hybrid EV charging system focusing on energy management and optimization. The study introduced a control strategy to efficiently distribute power between renewable sources and battery storage. Results demonstrated reduced grid dependency and improved energy efficiency. The authors emphasized the importance of intelligent control systems in managing renewable intermittency. The study concluded that optimized energy management enhances the overall performance of hybrid EV charging stations.

Ahmed and Hassan (2023) analyzed hybrid renewable energy-based EV charging systems with a focus on system integration and performance. Their research highlighted the benefits of combining solar, wind, and battery storage to ensure continuous energy supply. Simulation results showed improved system efficiency and reduced environmental impact. The authors concluded that hybrid renewable systems are a sustainable and reliable solution for future EV charging infrastructure.

Hassan and Ali (2021) conducted a performance analysis of solar–wind EV charging stations published in the Journal of Cleaner Production. Their research evaluated system behavior under various weather scenarios, including sunny, cloudy, and windy conditions. The results confirmed effective energy balance between renewable sources, storage, and EV loads. The study also reported a significant reduction in carbon footprint compared to grid-based charging stations. The authors concluded that hybrid renewable charging stations are environmentally sustainable and technically viable for large-scale deployment.

IV.

PROJECT DESCRIPTION

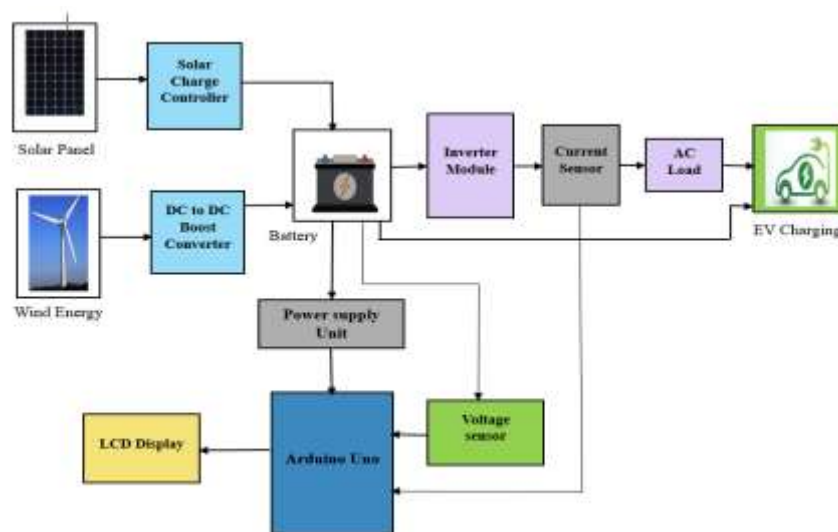


Fig. 3 Block Diagram of system

The system operates with its renewable energy system which combines a solar panel and a wind energy generator. Solar PV output gets treated with a solar charge controller which delivers safe battery charging and operational efficiency. The wind energy output gets transformed through a DC-DC boost converter which keeps the system at a stable DC voltage output. The battery bank receives energy from both solar and wind sources which function as energy storage and buffering systems. The inverter module receives DC power from the battery which it uses to generate AC power whenever needed. AC output from the system powers EV charging stations and other AC devices while DC power enables direct usage for DC charging. The system employs voltage and current sensors to track battery voltage and load current and power distribution throughout the system. The Arduino Uno controller processes sensor data to enable real-time monitoring and control functionality. The LCD screen shows the measured parameters which include voltage and current and battery status. The energy management algorithm gives main priority to renewable sources while only using grid power when the batteries reach their complete depletion point.

The Smart EV Charging Stations use a hybrid energy system which includes solar panels and wind turbines to provide continuous power. The energy generated by both sources is stored in batteries, which then supply power to charging stations. Wind turbines produce electricity whenever there is wind, and solar panels collect energy from sunlight during the day. The two systems can function together to produce their maximum electricity output.

Batteries function as essential components which guarantee continuous power delivery to enable EV charging during periods of low energy generation. The hybrid system requires a substantial upfront investment but its long-lasting design and extended operational life combined with minimal upkeep expenses make it an economically viable and environmentally friendly option.

The wind turbine generates DC power which an inverter transforms into AC power to enable compatibility with EV charging stations. The system adjusts its power output in response to current environmental conditions by choosing between two energy sources or selecting the most effective option available at the moment.

Hybrid-powered EV charging stations which use renewable energy sources decrease their reliance on fossil fuels while decreasing their carbon emissions and promoting environmentally friendly transportation. The solution provides an energy system which meets increasing electric vehicle needs through reliable green technology which operates autonomously.

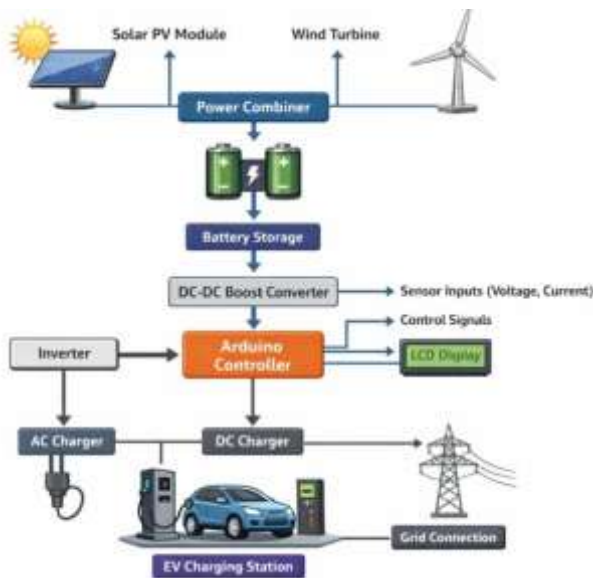


Fig. 4 Flow chart of working system

- **Solar PV Module:** Converts sunlight into electrical energy used for EV charging. It provides a clean, renewable power source, reducing dependence on conventional grid electricity and lowering carbon emissions.
- **Wind Energy Generator:** Generates electricity during windy conditions, complementing solar power. It enhances system reliability by ensuring energy availability even when sunlight is insufficient.
- **Battery Energy Storage System:** Stores excess energy produced from solar and wind sources. It ensures continuous EV charging during low generation periods and improves overall system efficiency.
- **DC-DC Boost Converter:** Regulates and maintains a stable DC voltage from fluctuating renewable inputs. It improves charging efficiency and ensures consistent power delivery to the system.
- **Inverter Module:** Converts stored DC power into AC power for AC loads and EV charging. It enables flexibility by supporting both AC and DC charging systems.
- **Arduino Microcontroller Unit:** Acts as the central control system. It manages energy flow, executes control algorithms, and coordinates all components for efficient operation.
- **Voltage and Current Sensors:** Continuously monitor parameters like voltage, current, and power flow. They provide real-time feedback for safe, reliable, and optimized system performance.
- **LCD Display:** Displays key system parameters such as voltage, current, and battery status. It improves user interaction and helps in easy monitoring of system performance.

V.

COMPONENTS SPECIFICATION

• **Solar Panel (12v25w)**

Solar energy is the energy that we receive from the sun in the form of radiation. It does not pollute and is infinitely renewable. It is accessible for free. A solar cell, sometimes called a photovoltaic cell, is a device that converts solar energy into electricity.



- **DC Generator (12v)**

A direct current generator, or DC generator, is a device whose principal job is converting mechanical power to electricity.



- **DC to DC boost Converter (Regulated 12v)**

A boost converter (or step-up converter) is a power converter from DC to DC that increases voltage while decreasing current from the input (supply) to the output (load). It is a type of switched-mode power supplies (SMPS) that has a minimum of two semiconductor components (a diode and a transistor) along with at least a single energy storage element: a capacitor, an inductor, or both in combination.



- **Inverter (12v DC to 220v AC)**

As we all know, most electrical devices require AC power, thus the direct current (DC) power of the batteries is transformed into AC voltage using an inverter before being transmitted to the loads. The inverter has to be having excess voltage protection, the opposite polarity, as well as short circuit protection.



- **Battery (12V 5Ah)**

Batteries are used to store the power generated by piezoelectric and solar energy. The capacity of the battery might vary based on the dimension of the input power produced.



VI.

ADVANTAGES

- In rainy and winter season the amount of solar radiation is not sufficient than in this season energy is fulfilled by wind energy system.

- Due to variation in weather condition when there is lack of wind energy than the power is supplied by the solar panels.
- Low operating cost and maintenance cost makes it economical.
- Used in any location whether it is remote area or populated area.
- Highly efficient power generation
- Solar- and wind-powered sites benefits the environment as it will reduce the carbon and other harmful emission is about 90% in environments.

VII.**APPLICATION**

- Distributed power generation
- Hospital, Hotels, Guesthouse etc.
- Remote and Rural area Electrification.
- Street lighting.
- Transmission and communication Tower and many more application.

VIII.**SCOPE OF PROJECT**

- It is the design method for maximum conversion efficiency of a turbine for delivering the maximum power to a load, battery in the case of a standalone solar-wind system.
- Saves space.
- It doesn't require fuel.

IX.**CONCLUSION**

The smart electric vehicle charging station which uses a hybrid solar-wind power generation system will provide sustainable and efficient and dependable electric vehicle charging solutions for upcoming charging requirements. The system achieves its goal of reducing fossil fuel dependency through its ability to operate with renewable energy sources and battery storage and power electronic converters and intelligent energy management systems. The system achieves real-time monitoring through its use of sensors and an Arduino-based controller which maintains stable voltage control and enables efficient power distribution while protecting system safety during different load and weather situations. The system provides users with increased options through its dual AC and DC charging capabilities which improve operational flexibility. The proposed model enables environmentally friendly transportation solutions which decrease electric grid demand during peak times while providing a renewable energy-based electric vehicle charging network that can be expanded to smart cities and distant areas.

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