# Renewable Energy in EV Charging Infrastructure: Advancements and Challenges

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**Abstract:** *The synergy between renewable energy sources and electric vehicle (EV) charging infrastructure signifies a transformative step towards sustainable transportation. This review explores the paradigm shift towards utilizing solar, wind, and hydroelectric power for charging stations, aiming to mitigate greenhouse gas emissions and enhance energy sustainability. We discuss the advantages and challenges of renewable energy integration in EV charging infrastructure, including environmental benefits, energy independence, and cost savings. Furthermore, we delve into standalone plugin EV charging stations, focusing on their significance, operation modes, and technological advancements. Additionally, the paper provides insights into EV charging technology, covering different power levels, costs, and merits of various charging modes, from Level 1 to Level 3. Overall, this review offers a comprehensive understanding of the evolving landscape of renewable energy-powered EV charging infrastructure and its implications for the transition to a cleaner and more sustainable transportation ecosystem.*

**Keywords:** *Renewable energy, electric vehicle charging infrastructure, standalone plugin charging stations, EV charging technology, sustainable transportation..*

## I. INTRODUCTION

Renewable energy, electric vehicle charging infrastructure represents a pivotal intersection between sustainable energy practices and the evolving landscape of transportation. This innovative concept embodies the fusion of renewable energy sources with purpose-built charging stations tailored for sources like solar, wind, and hydroelectric power, this paradigm seeks to revolutionize the way EVs are powered and charged [1-2].

The integration of renewable energy into EV charging infrastructure is motivated by a dual imperative: to mitigate the adverse environmental impacts associated with transportation and to foster energy sustainability. Traditional fossil fuel-powered vehicles are notorious contributors to greenhouse gas emissions, exacerbating climate change and air pollution [3]. In contrast, the utilization of renewable energy sources for EV charging endeavors to curb these emissions, reducing the transportation sector's reliance on finite and environmentally harmful fossil fuels.

At the heart of this concept lies the harnessing of renewable energy sources to power EV charging stations, thereby facilitating a transition towards a greener and more sustainable transportation ecosystem [4]. Solar-powered charging stations harness the abundant energy of sunlight through photovoltaic panels, while wind-powered stations tap into the kinetic energy of wind using turbines. Similarly, hydroelectric charging stations leverage the power of flowing water to generate electricity, offering a diverse array of clean energy options for EV charging.

The adoption of renewable energy for EV charging infrastructure promises a multitude of advantages. Beyond the obvious environmental benefits, including reduced carbon footprints and lower emissions, this approach offers energy independence by diversifying the sources of electricity used for transportation. Additionally, the long-term cost savings associated with renewable energy, coupled with the potential for revenue generation through grid integration, make this concept economically appealing [5].

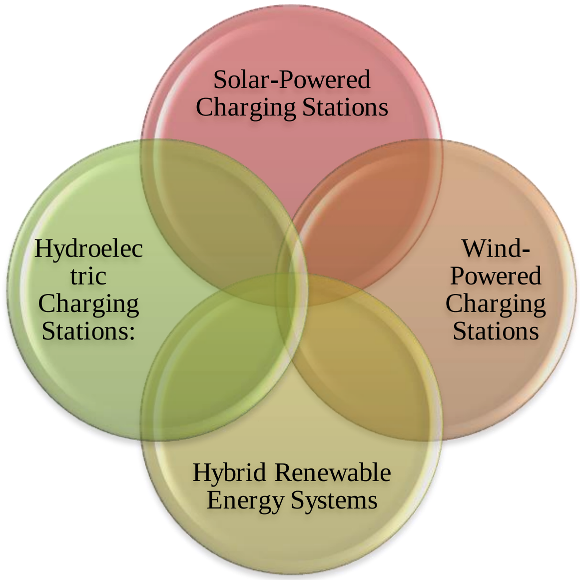


Fig. 1 Hydroelectric Charging Stations: Hybrid Renewable Energy Systems

**Advantages**

- Environmental Sustainability: Utilizing renewable energy sources such as solar, wind, and hydroelectric power for EV charging reduces greenhouse gas emissions and mitigates the environmental impact of transportation.
- Energy Independence: By harnessing renewable resources, countries can reduce their reliance on imported fossil fuels, enhancing energy security and resilience.
- Cost Savings: Renewable energy is often cheaper and more stable in cost compared to fossil fuels, leading to potential cost savings for EV owners and charging station operators.
- Scalability and Accessibility: Renewable energy infrastructure can be deployed at various scales, from residential solar panels to utility-scale wind farms, providing accessible and decentralized energy solutions for EV charging.

**Disadvantages**

- Intermittency and Variability: Renewable energy sources are inherently intermittent and dependent on weather conditions, posing challenges for consistent EV charging and grid stability.
- Initial Investment Costs: The upfront costs of installing renewable energy systems and EV charging infrastructure can be significant, requiring substantial investments in equipment and installation.
- Grid Integration Challenges: Integrating renewable energy sources into existing electrical grids may require upgrades and modifications to accommodate fluctuating power generation and EV charging demand.
- Land and Resource Use: Large-scale renewable energy projects, such as solar farms and wind turbines, may require significant land area and natural resources, leading to environmental concerns and land use conflicts.

## II. STANDALONE PLUGIN ELECTRIC VEHICLE CHARGING STATION

Standalone Plugin Electric Vehicle Charging Stations represent a crucial component of the infrastructure required to support the widespread adoption of electric vehicles (EVs). These charging stations are designed to provide a convenient and accessible means for EV owners to recharge their vehicles, particularly in urban areas, commercial spaces, and public locations. Unlike traditional fuel stations, standalone plugin EV charging stations rely solely on electricity as a power source, eliminating the need for fossil fuels and reducing greenhouse gas emissions associated with transportation. As the demand for EVs continues to rise, the deployment of standalone plugin charging stations becomes increasingly important in promoting sustainable transportation and reducing reliance on traditional internal combustion engine vehicles. This introduction will explore the significance of standalone plugin EV charging stations, their advantages and challenges, and their role in facilitating the transition to a cleaner and more sustainable transportation ecosystem. A standalone or remote hybrid PEV charging station is a station used to charge the EVs in remote areas using power generated from independent renewable energy resources only without having any interconnection with the conventional grid systems. The basic structure of a standalone hybrid PEV charging station with an integrated storage system.

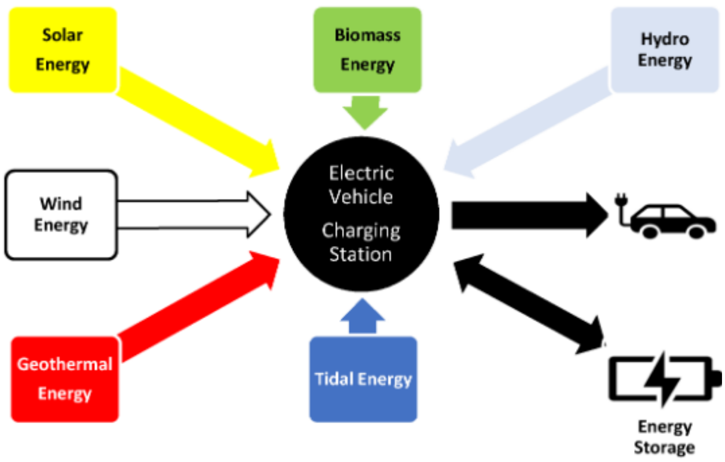


Fig. 2. RE-based standalone plugin electric vehicle charging station.

This system employs green energy for electricity generation and has storage to cover up the uncertainty of these REs while improving the charging time. The infrastructure of an electric vehicle charging station falls under four major categories, named (1) charging station without ESS, (2) charging station with ESS, (3) charging station with REs, ESS and grid integration, and (4) charging station with REs, ESS without grid supply. This paper is focused on ESS configurations in EV charging stations with REs; ESS but without the grid supply.

There can be different modes of operations in a standalone charging station, such as generation to vehicle (G to V), generation to storage (G to ESS), storage to vehicle (ESS to V), vehicle to storage (V to ESS), and vehicle to vehicle (V to V). Storage involved with these charging stations can also be of different types depending upon the sources of generation and storage time requirements.

## III. LITERATURE REVIEW

K. Karmaker et. al. (2023)[6] introduces an energy management algorithm for a hybrid solar and biogas-based electric vehicle charging station (EVCS) that considers techno-economic and environmental factors. The proposed algorithm is designed for a 20-kW EVCS and uses a fuzzy inference system in MATLAB SIMULINK to manage power generation, EV power demand, charging periods, and existing charging rates to optimize real-time charging costs and renewable energy utilization. The results show that the proposed algorithm reduces energy costs by 74.67% compared to existing flat rate tariffs and offers lower charging costs for weekdays and weekends. The integration of hybrid renewables also results in a significant reduction in greenhouse gas emissions, with payback periods for charging station owners being relatively short, making the project profitable.

Karmaker, A. K., et. al. (2018) [7] The rapid increase in electric vehicle (EV) in Bangladesh requires more energy to run these vehicles. Moreover, the transportation sector produces Green House Gas (GHG) especially CO2 emissions. Due to the excess power needed to recharge these EVs, the national grid has to supply more than 500 MW daily. This paper proposes an Electric Vehicle Charging Station (EVCS) based on solar and biogas to reduce the burden on the national grid. The proposed EVCS integrates a combination of a solar PV module (10 kW), three biogas generators (10 kW), 25 lead acid batteries (each 100 Ah), a converter (10 kW) and charging assemblies. This paper analyzes the technical, economic and environmental feasibility of the proposed EVCS using the Hybrid Optimization of Multiple Energy Renewables (HOMER) Pro software. This configuration estimates a Cost of Energy (COE) of $0.1302/kWh, total net present cost (NPC) of $56,202 and operating cost of $2540. In addition, the proposed model reduces the CO2 emissions by 34.68% compared to a conventional grid-based charging station. The designed EVCS saves approximately $12–$18 per month to recharge an EV which increases the socio-economic standard of EV owner.

Das, H. S.,et. al. (2020) [8]Transportation electrification is one of the main research areas for the past decade. Electric vehicles (EVs) are taking over the market share of conventional internal combustion engine vehicles. The increasing popularity of EVs results in higher number of charging stations, which have significant effects on the electricity grid. Different charging strat2egies, as well as grid integration methods, are being developed to minimize the adverse effects of EV charging and to strengthen the benefits of EV grid integration. In this paper, a comprehensive review of the current situation of the EV market, standards, charging infrastructure, and the impact of EV charging on the grid is presented. The paper introduces the current EV status, and provides a comprehensive review on important international EV charging and grid interconnection standards. Different infrastructure configurations in terms of control and communication architectures for EV charging are studied and evaluated. The electric power market is studied by considering the participation roles of EV aggregators and individual EV owners, and different optimization and game based algorithms for EV grid integration management are reviewed. The paper specially presents an evaluation on how the future EV development, such as connected vehicles, autonomous driving, and shared mobility, would affect EV grid integration as well as the development of the power grid moves toward future energy Internet and how EVs would affect and benefit the development of the future energy Internet. Finally, the challenges and suggestions for the future development of the EV charging and grid integration infrastructure are evaluated and summarized.

Lee, J., et. al. (2017) [9] describes a big data analysis strategy for electric vehicle charging infrastructure, mainly built upon open data sets and open software components. The data acquisition module periodically retrieves the real-time status information of each charger from the public data portal, while the downloaded XML files are parsed to extract fields of interest. At this stage, we present the distribution of charging facilities in Jeju City based on our own map viewer implementation, the city-wide dynamics of the number of chargers in operation based on MySQL queries, and the visualization of regional occupancy rates based on the R GISTools library. After combining a variety of statistical and machine learning techniques to understand the demand pattern of electric vehicle charging, we will integrate renewable energy to charging-intensive power grids as much as possible.

Seddig, K., et. al. (2017) [10] Electric vehicles are one of the concepts towards green and sustainable transportation systems. However, several uncertainties with respect to electricity demand and availability of electric vehicles as well as electricity supply by renewable energy sources influence an optimal scheduling through smart charging strategies. This paper investigates the possibilities to integrate additionally loads of uncertain renewable energy sources by smart charging strategies of three different electric vehicle fleets namely, com mercial customers, commuters, and opportunity parkers. Therefore, data from an empiric field test with a public charging infrastructure in a parking garage with a photovoltaic system is taken. Various stra tegies are analyzed, considering the changing individual electricity demand, restrictions and parking times of electric vehicle fleets by combining a Monte Carlo simulation approach with different meth odologies like a heuristic algorithm, an optimization model and stochastic programming. The numerical results indicate that the domestic photovoltaic generation of the car park can be fully used by the electric vehicle fleets for charging and the utilization of photovoltaic can be doubled when comparing uncon trolled and optimized charging strategies. The commuter fleet has the highest CO2 emission reduction potential of all three electric vehicle fleets. Moreover, load management decreases costs, even when uncertainties are considered.

Foley, A. M., et. al. (2010) [11] The international introduction of electric vehicles (EVs) will see a change in private passenger car usage, operation and management. There are many stakeholders, but currently it appears that the automotive industry is focused on EV manufacture, governments and policy makers have highlighted the potential environmental and job creation opportunities while the electricity sector is preparing for an additional electrical load on the grid system. If the deployment of EVs is to be successful the introduction of international EV standards, universal charging hardware infrastructure, associated universal peripherals and user-friendly software on public and private property is necessary. The focus of this paper is to establish the state-of-the-art in EV charging infrastructure, which includes a review of existing and proposed international standards, best practice and guidelines under consideration or recommendation.

## IV. EV CHARGING TECHNOLOGY

An overview of different power levels, costs, merits, and demerits of various charging technology is discussed. The charging time of an EV depends mainly on the charging level of the battery. Besides, it also depends on the ability of the EV battery to accept a high charging rate, the cable used for charging, and the Electric Vehicle Supply Equipment (EVSE). EVSE is the “point-of-fuelling” infrastructure used to deliver electrical energy to the charger, also called an electric re-charging unit. It consists of various components such as charging cords, ports, connectors, and interfaces to charge the battery. Different charging modes/levels are classified by the international standard IEC 61,851, the Electric Power Research Institute (EPRI), the Society of Automotive Engineers (SAE) [14], and the International Electro-Technical Commission (IEC) [13], namely alternating current AC - Level 1, Level 2, Level 3, and Direct Current DC level 4 [15].

The EPRI report disclosed that EV users are willing to charge their EVs after arriving home, particularly at night [17]. Thus, AC level 1 (slow) charging is preferred for EV charging at home [16] and is called overnight or residential. Further, the slow charging equipment is suitable for fixing typical wall outlets at home. In the level 1 charging mode, electric power is converted from AC to DC by the vehicle’s onboard charger [18]. However, this power conversion may not be the same in every region/country because of various standards and frequency.

### 2.1. Level-1 charging

In North America, a standard 120 V/15 A single-phase outlet grounded, such as NEMA 5-15R, is used as a level-1 charging, and this connection operates with the standard SAE-J1772 connector. The current handling capacity of this mode has two options, either 15 A (12 A usable) or 20 A (16 A functional), and it can draw from 1.4 kW to 1.9 kW of power. This mode will take an average of 8–12 h to reach 100 % battery State of Charge (SOC). The advantage of the level-1 charging mode is that no additional infrastructure is required for homes and office sites; hence it is economical. The total cost of a level-1 charging infrastructure has been reported as approximately 400–900 USD. However, support for communication control is not available. So, it could not consider the grid load and load quality when connected to the grid. As a result, many level 1 charges could negatively impact the grid, such as grid power congestion.

### 2.2. Level-2 charging

Level 2 charging mode is the most suitable option for private charging facilities. For private installation, this mode assigns a single-phase 240 V AC with a current-handling capacity of 40 A and 80 A for a 400 V (three-phase) AC supply. Because of standardized vehicle-to-charger connection and less charging time than mode-1, EV users are likely to prefer mode-2 charging technology. A residential infrastructure installation of mode-2 technology reportedly costs approximately 2,150 – 2,300 USD. Furthermore, the quickest car in the world “Tesla Roadster” charging system, is reported to add a cost of 3,000 USD. The mode-2 charging is advantageous, as the supplied equipment and the office/warehouse appliances can operate with the same circuit (i.e., electric ovens). Users can utilize a “temporary-use cable” provided by the supplier to charge EV batteries outside their homes. It can communicate with the car and can contribute toward grid stability. The cable can protect itself from the issues such as overcurrent and over-temperature. This charging mode usually takes 4–8 h to charge the battery, which is better than mode-1 charging. Commercial and public charging stations cost more than 15,000 USD. Thus, the infrastructure installation cost is cheaper than the commercial charging infrastructure. Though mode-2 charging has many advantages, it has certain drawbacks, such as the power consumption can surge up to 25 %.

2.3. Level-3 charging

A few years ago, SAE developed a fast-charging option to charge an EV battery capacity of 130 kW, using 480 V(AC) with a considerable quantity of high current, standard in commercial and industrial locations. Therefore, highway rest areas and city refueling points, such as malls, airports, parks, motels, petrol pumps, and other public places, are suitable for installing level 3 charging. It can enable the EV user to charge the EV while performing other tasks. A Japanese protocol for “CHAdeMO” (move using charge) is gaining international recognition for quick charging via a special electrical connector. In the EU, Combined Charging System connectors are recommended to install in Fast Charging Station (FCS).

## V. CONCLUSION

The integration of renewable energy into electric vehicle charging infrastructure represents a pivotal step towards achieving sustainable transportation goals. By harnessing solar, wind, and hydroelectric power for EV charging, countries can reduce their reliance on fossil fuels, mitigate greenhouse gas emissions, and enhance energy security. Standalone plugin EV charging stations offer convenient and accessible charging solutions, further accelerating the adoption of electric vehicles. Despite challenges such as intermittency and initial investment costs, advancements in EV charging technology and grid integration are facilitating the transition towards a greener transportation ecosystem. Future research should focus on addressing these challenges and maximizing the potential of renewable energy integration to drive widespread EV adoption and combat climate change.

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