IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

Review of Hybrid Powered EV Charging Systems

Siddiqui Ayesha Abutalib, Gire Shruti Sanjay, Dr. T. M. Dudhane
Dept of Electronics and Telecommunication Engineering,
Rajgad Technical Campus, Engineering, Dhangwadi, Pune, India
siddiquiayesha8312@gmail.com, shrutigire8@gmail.com, tmdudhane@gmail.com

Abstract: *The increased popularity of the use of the electric vehicles (EVs) resulted in establishment of the increasing demand of efficient charging infrastructure. Traditional EV charging of grid could lead to grid congestion, operational cost increase and carbon emissions. The solution to these problems has been cited to be the use of EV charging systems through the use of the hybrid engines using the renewable energy sources in the form of solar photovoltaic (PV) and wind energy, together with power storage. The focus of the current paper is a critical review of the hybrid EV charging systems with the consideration of the use of the renewable energy, energy management, optimization, and intelligent control. They are photovoltaic-battery-grid, solar-wind hybrid and distributed renewable-based charging stations, which are studied. The review indicates the current advancements in optimization algorithms, control by artificial intelligence, and techno-economic analysis to improve charging efficiency and reliability. Moreover, gaps in the research, including scalability, financial viability, and deployment issues in the real world, are addressed. The results of this review will help create a robust and sustainable EV charging system..*

Keywords*:* electric vehicles, hybrid charging station, renewable energy, solar photovoltaic, energy management system, and smart grid

I. INTRODUCTION

The transport industry is one of the largest sources of greenhouse gases and other environmental pollution. Rapid urbanization, industrial development, and increased vehicle numbers have strained fossil fuel supplies, leading to serious environmental and financial issues. Traditional internal combustion engine cars are mostly dependent on petroleum-based fuels, thus contributing to carbon dioxide emissions, air pollution, and climate change. As a result, the entire world is making greater efforts to switch to cleaner, more sustainable transportation technologies. Electric vehicles (EVs) are among the potential solutions to these problems, thanks to their increased energy efficiency and zero tailpipe emissions. Increased awareness of environmental issues and stringent governmental policies worldwide have boosted market adoption of EVs. Numerous nations are encouraging the implementation of EVs through subsidies and financial support, as well as establishing charging networks. Additionally, the battery systems and particularly lithium-ion batteries are technologically advanced with a resultant higher driving range, better charging efficiency and reliability of EVs. All these technological achievements notwithstanding, the mass acceptance of EVs will require the creation of a sustainable, long-term system of a charging infrastructure that can support the growth of energy demand.

The other reason why some people should create high EV charging systems is that they have to decrease reliance on electricity generated from fossil fuels. Even though EVs do not produce pollutants during operation, the electricity required to recharge the batteries might be generated by fossil-fuel-powered power plants. Thus, combining renewable energy sources into EV charging infrastructure is a crucial requirement for achieving a fully sustainable transportation system. EV charging systems powered by hybrid renewable and grid power sources, along with energy storage technologies, have been developed as a potential solution to these problems.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

A. Growth of Electric Vehicles and Charging Demand

The global electric vehicle (EV) market has grown rapidly over the last 10 years due to technological developments, environmental concerns, and favorable government policies. Numerous car manufacturers are investing heavily in EV development and launching new models to meet growing market demand. According to recent industry reports, the global EV fleet is expected to grow significantly over the next few years, driving a sharp increase in electricity demand for EV charging.

As the number of EVs grows, the need to charge them is increasing rapidly. There are charging stations, residential charging units, and fast-charging networks that are being designed to facilitate the growing EV ecosystem. Nevertheless, concurrent charging of a set of vehicles can cause a peak in electricity demand, placing additional strain on the current power grid. This will be of particular concern in large city regions with high EV adoption rates. Moreover, technologies that charge very quickly and are designed to shorten charging time demand high power levels, which can cause grid and voltage instability unless addressed. Thus, it has become a priority to develop a superior charging infrastructure capable of handling high-power charging without compromising grid stability. The use of hybrid-powered EV charging systems with renewable energy sources and energy storage technologies provides a viable solution to the growing demand for charging and to reduce the load on utility grid.

B. Limitations of Conventional Grid-Based Charging Systems

Traditional EV charging stations depend mostly on utility-grid electricity. Although the grid-based charging infrastructure is reliable for delivering power, it also poses various technical and environmental challenges. A key drawback is that EV charging on a large scale will put a strain on the power grid. When multiple vehicles are charged in parallel, especially during peak demand, the grid is likely to be stressed, leading to voltage instability and possibly power quality issues.

Another weakness is the dependence on centralized electricity production by the grid-based systems. In the majority, plants that use of coal, natural gas and oil plants, are used to the generate electricity in high percentages. Thus, the advantages of electric cars to the environment can be partially compensated by electricity production emissions. This issue highlights the need to use renewable energy sources to charge EVs. In addition, the grid-based charging system would require the heavy investments into the power distribution system, transformers, and rows. The existing grid infrastructure may be expensive and logistically difficult to upgrade to support the use of high-power EV chargers. These limitations have led scientists and technologists to identify new means of charging batteries that will not render the grid dependent but will improve sustainability and efficiency of energy.

C. Role of Renewable Energy in EV Charging

Green energy is critical towards the development of sustainable EV chargers. Use of the renewable energy technologies such as the solar photovoltaic systems, wind turbines, and fuel cells into EV charging stations will go far in ensuring that carbon emissions are minimal and that the use of fossil fuels to generate electricity is reduced. Renewable power charging stations also promote energy security through the utilization of the local energy.

The solar photovoltaic systems have been extensively used in the EV charging due to their low cost, their prices have been lowered and they provide clean power. The solar-charging EV stations will be able to create energy when the sun is up and retain any excess in battery systems to be used at a later time. Wind power can be used to support solar power generation to produce electricity when the sun is low thus improving the reliability of the entire system in terms of power charges. The amalgamation of energy sources that are renewed with energy storage technologies makes it possible to manage efficiently the power production process and consumption. Energy storage plants will keep excess renewable energy when renewable production is the highest and will release the energy when the power demand is the highest or when the production by renewable sources is inadequate. This will enhance the stability as well as efficacy of the EV charging systems more so the exploitation of renewable energy resources to the maximum extent.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

D. Need for Hybrid Powered EV Charging Systems

Although the sources of renewable energy provide clean and sustainable electricity, the intermittency has complicated the supply of power at all times. Solar and wind energy is dependent on the environment, which can vary at any given time e.g. sunlight and wind speed. Thus, the intermittent power supply can be caused by the use of renewable energy as the only source of charging EVs.

This is addressed by adopting hybrid-powered EV charging systems that have integrated various energy sources, such as energy storage systems, renewable energy systems and the conventional grid. The hybrid systems will offer a stable power supply by supplementing the other sources of power and simplifying the use of energy. To give an example, power can be generated throughout the day by a solar photovoltaic system, but at night or on a cloudy day a battery storage system can be used to supply power. Renewable energy storage and production is not necessarily enough to maintain the utility grid as an emergency supply.

Charging of hybrid electric vehicles also improves the efficiency of energy by using smart energy management devices that simplify the process of distributing power among different energy sources. Advanced control algorithms have the ability to dynamically control the energy resources in accordance with charging demand, availability of renewable energy, and grid conditions. This will increase the reliability of the system and minimize the costs of operation and environmental effects.

E. Scope and Contributions of the Review Paper

The increasing rate of switching to electric automobiles and the proliferation of the need to adopt sustainable charging systems have prompted excessive research on hybrid-driven charging systems. Some of the studies have examined different characteristics of the hybrid charging system and these characteristics comprise the development of renewable energy, power electronics, energy management, optimization algorithms, and techno-economic analysis. However, sources in question are widely dispersed in different spheres of study, and it is difficult to obtain the clear picture of the contemporary development. The review article is a logical examination of the essence of the hybrid-powered EV charging systems based on existing research contributions in the field. The paper will address several types of hybrid system designs that will be targeted at integrating sources of renewable energy, energy storage technologies, and grid links to charge EV. Besides, the review also discusses various categories of energy management strategies and optimization techniques that have been utilized to enhance the performance and reliability of the system.

The other contribution of the current work that was helpful is the identification of research gaps and challenges associated with charging infrastructure of hybrid EVs. The issues on intermittency, scalability, economic viability, and practical application of renewable energy are discussed. Finally, this paper goes further to suggest the potential research directions to increase the efficiency, sustainability, and scalability of hybrid-powered EV charging systems. Through this comprehensive review, the review is likely to help the researchers, engineers, and policymakers to come up with better EV charging solutions to support a sustainable transportation ecosystem.

II. ARCHITECTURE OF HYBRID EV CHARGING SYSTEMS

Hybrid electric vehicles (EVs) are electric powered vehicles that are charged using renewable energy to offer sustainable electricity. Having a new source of energy will help the greenhouse gas to be minimized to the bare minimum, and dependence on the conventional grid electricity will be minimized. Solar, wind and bioenergy systems are among the renewable sources that are available in the electric vehicle charging infrastructure.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

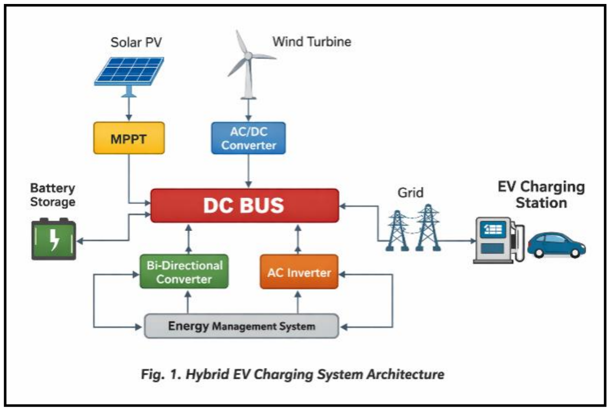

Fig. 1. Hybrid EV Charging System Architecture

A. Components of Hybrid Charging Systems

The idea of a hybrid electric vehicle (EV) is to combine multiple energy sources and advanced control systems to provide stable, efficient, and sustainable charging. Most of these systems combine components that work together to generate, store, convert, and distribute electrical energy to EVs. The following are the key components: renewable energy generation units, energy storage units, power electronic converters, charging infrastructure, and energy management systems.

Facilities that produce renewable energy use renewable resources such as solar, wind, and biomass. These offer clean energy whose use can be employed to reduce reliance on electricity production, which relies on fossil energy. Energy storage systems are mounted on hybrid charging stations to store excess renewable energy and supplement renewable production or meet power demands during periods when renewable production is insufficient or when the charging load is high. Storage technologies also stabilize the system and maintain voltage and frequency.

Power electronic converters direct and regulate the circulation of electricity between the components of the system. These converters provide power within the voltage and current ranges of the EV charging units. In addition, the charging stations have a communication and monitoring system, which the operators can utilize to monitor the charging process, distribution of energy, and performance of the system. All these factors imply that hybrid charging systems can provide reliable, efficient EV charging services and optimize the use of renewable energy.

B. Renewable Energy Sources for EV Charging

Hybrid electric vehicle (EV) charging systems use renewable energy to provide sustainable charging electricity. With the advent of a new energy source, greenhouse gas emissions will be reduced to the lowest possible level, and reliance on the traditional grid electricity will decrease. Renewable sources used in electric vehicle charging infrastructure include solar, wind, and bioenergy systems.

Solar Photovoltaic Systems

One of the most popular renewable energy technologies for charging EV stations is solar photovoltaic (PV). The photovoltaic effect is the conversion of sunlight into electrical energy using photovoltaic panels. The solar-based charging stations also have appeal due to their scalability, lower installation costs, and comparatively straightforward integration into EV charging infrastructure. PV panels produce electricity during daylight hours, which can be used directly in EVs or stored in battery energy storage systems for later use. Maximum Power Point Tracking (MPPT) algorithms are usually used in solar charging systems to optimize energy collection based on the varying environmental conditions, including the like of variations in temperature, as well as intermittent solar irradiance. Solar powered EV stations shall be particular in urban locations, parking areas and home charge.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

Wind Energy Systems

Wind energy systems are another highlight of renewable energy sources that can be used to charge the hybrid EVs. The wind turbines are employing the moving energy of wind so as to produce the electrical energy through the mechanical rotation of turbine blades attached to the electrical generating machines. Solar energy can be supplemented with wind energy, as during the night or in cloudy seasons, the wind speeds tend to be high, whereas the production of solar energy is rather low. The presence of wind turbines within EV charging stations will increase the degree of reliability of the whole system because of the diversification of the energy sources. Especially solar-wind charging systems are very helpful in locations where there is both solar and wind energy. These systems are capable of generating electricity in varying weather conditions and thus this reduces the issue of intermittency of individual renewable energy sources.

Fuel Cells and Biogas Systems

There is also a debate on the fuel cells and biogas as an alternative energy source in EV charging stations. The electrochemical reaction of hydrogen and oxygen forms electricity produced by the Fuel cells and water is the only byproduct. Fuel cell vehicles are highly efficient and can deliver power to the vehicle continuously in the event of hydrogen fueling. Biogas systems involve the conversion of organic waste (e.g. agricultural residues, food waste, or animal manure) by anaerobic digestion into methane gas. Biogas generated can be used to fuel the generators used to produce electricity to charge EVs. Such systems will generate another renewable energy source particularly in the rural areas where there is easy access to biomass resources. Fuel cells or biogas generators can be added to enhance reliability and sustainability of the energy of the hybrid EV charging systems.

C. Energy Storage Technologies

Also applicable in the charging system of hybrid EV is energy storage that will overcome the intermittency of the development of the renewable energy source and provide continuity to power supply when the renewable energy source is high or when the power demand is high or when the renewable energy source is low.

Battery Energy Storage Systems

The hydrid charging station is equipped with battery storage units that allow it to store the excess renewable energy generated when the solar or wind generation is greater than required and avail it to the EVs when the renewable generation reduces. Power stabilization Battery systems can also be applied to stabilize a grid, i.e. to even out power peaks and maintain a constant voltage at all times. The bidirectional battery also has the ability to enable other more sophisticated functions such as the vehicle to grid (V2G), where EV batteries can sell electricity to the grid when the demand is high.

Supercapacitors

Supercapacitors (also ultracapacitors) are high-energy storage devices, which are characterized by high power density and rapid charge and discharge. Unlike conventional batteries, supercapacitors hold the energy in the form of an electrostatic charge as opposed to a chemical reaction. This is what allows giving them a high power burst in a short period. In hybrid charging systems, the batteries are normally used with supercapacitors since they require handling high load variations and fast charging. This is due to the fact that they react fast to changes in power demand aiding in improving the stability of the system and reducing stress on the battery storage units.

Flywheel Energy Storage Systems

Flywheel systems have such attributes as high efficiency, long service life, and low maintenance. Short-term changes in renewable energy production or in charging batteries of hybrid EVs may be solved with the help of flywheel storage. Flywheel systems are not well received compared to battery storage technologies, but they provide a decent option to high-power applications that require a rapid response to energy.

D. Power Electronics and Converter Technologies

Power electronics have been critical in the process of charging batteries of hybrid electric vehicles (EV) and in the regulation and control of power flow to and from the renewable energy sources, storage systems, the grid, and the EVs. To ensure effective energy conversion and voltage management across the charging system, multiple converter technologies are employed.

DC-to-DC converters are typically used for voltage regulation across photovoltaic panels, battery storage systems, and EV batteries. Such converters enable the extraction of maximum power from renewable sources and ensure optimal charging conditions. To enable bidirectional energy flow between storage systems and the grid, bidirectional converters offer advanced functionality, including vehicle-to-grid and grid-support capabilities. Moreover, a DC-to-AC inverter converts direct current to alternating current for grid-connected operation by renewable energy sources. Innovative converter topologies have also been proposed to enhance system efficiency, reduce harmonic distortion, and improve overall power quality in hybrid EV charging systems, including zeta-, boost-, and multilevel converters.

E. Grid-Connected and Off-Grid Charging Configurations

The charging systems of hybrid electric vehicles (EV) can be in grid connected or off-grid, based on the utility grid infrastructure availability, and the objectives of the system design. In grid connected charging systems, the storage systems and the renewable energy resources are harnessed and linked with the utility grid. In the case of a high renewable generation, any part that is surplus can be sold to the grid, and in the case of an insufficient renewable generation, the grid can supply supplementary energy. Off-grid charging technology does not rely on the utility grid and instead is supplied by renewable energy and energy storage technology. These systems will particularly be applicable in remote areas where the grid facilities might not be adequate or exist at all. Hybrid charging stations of an off-grid type typically have the capability to integrate solar photovoltaic systems, wind turbine, and battery storage equipment to provide a power supply.

The hybrid microgrid EV charging system is a progressive approach to integrating multiple renewable sources, storage devices, and charging loads into a localized energy network. Such systems are more flexible, more resilient, and energy-independent, and enable sustainable EV charging infrastructure.

III. LITERATURE REVIEW

In [1], Cheikh et al. have studied one of the hybrid photovoltaic-battery-grid systems in electric vehicle charging stations. It operates with maximum power point tracking (MPPT) to maximize the solar energy harvesting, battery storage, and connection to the power grid to maintain a stable operation. The outcomes reflected improved energy distribution and reduced reliance on fossil fuels. Nonetheless, the scalability, financial viability, and practical implementation issues of the suggested system were not discussed in the given study.

Waheed et al. [2] developed and simulated a 4-kW solar-hybrid EV charging station using MATLAB and PVsyst. The system incorporated photovoltaic panels and battery storage, with grid connection, to ensure charging can be done consistently regardless of environmental conditions. The simulation results showed that 7635.3 kWh of energy were produced annually and that charging several EVs was possible. The traditional MPPT techniques, however, have been shown to have shortcomings in partial-shading conditions.

To address the problem of the intermittency of any individual renewable source, Vidyasagar et al. [3] suggested a solar-wind hybrid electric vehicle charging station modeled in MATLAB/Simulink. Well-fitted photovoltaic panels and wind turbines enhanced the reliability of the energy supply and the charging efficiency. The system proved able to supply energy consistently despite changing weather patterns. However, scalability, economic feasibility, and operational issues in practical implementations were not mentioned in the study.

Yadav et al. [4] proposed an MPPT algorithm-based grid-linked ability of a hybrid solar-wind EV charging station grounded on a power management scheme that would allow the maximum utilization of renewable energy. The effectiveness of the system was verified by real-time simulations about the OPAL-RT platform. The hybrid energy

IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429 Volume 6, Issue 8, March 2026 Impact Factor: 8.2

system reduced dependency on the conventional energy systems. However, there was no critical analysis of the problem of integration, as well as realistic limitations of the system in the paper.

On the hybrid EV charging station, Baccouche et al. [5] suggested a hybrid station comprises photovoltaic panels, batteries and a fuel cell, which is on the basis of high frequency optimized inverter technology. The system maximizes the power conversion to enhance efficiency and sustainability in transmission of energy. The presented findings improved power delivery and uniform EV charging functionality. It, however, failed to address the question of whether the system would be economically viable, the complexity of the system, and the challenges of implementing the system on a large scale.

Singla et al. [6] established a hybrid EV charger station that would utilize solar energy, which would be a combination of photovoltaic panels and battery energy storage to ensure continuous charge. The five working modes, as well as charging 10-12 EVs, were confirmed by the results of the simulation. The system also helped in selling overcapacity solar energy to the grid. The study however indicated the possibility of grid overloading during high demand high charging periods.

In [7], scientists have proposed an EV charging station that integrated solar and wind energy and battery storage devices. The system used advanced control algorithms to ensure the optimization of the use of renewable resources and stable charging processes. The results indicated the increased stability and the reliability of EV charging infrastructure. However, these issues as scalability, economic, and real-life implementation limitations were not discussed in detail in the study.

Suchithra and Sadanandam [8] suggested the use of a distributed EV charging station working on the basis of photovoltaic system and fuel cells attached on a shared DC bus. A PID controller was a fractional-order controller that contributed to the stability and regulation of voltage in the system. The system was found to be effective both in the grid-connected and islanded mode. However, the experiment failed to test the complexity of the implementation and how the controllers would perform with the real world disturbance.

Kumar and Rajan [9] suggested hybrid renewable energy system, which is a photovoltaic system and wind energy with sophisticated control mechanisms to use in charging EV. The result of simulation and lab experiment showed that the converter efficiency is 93.04% and the harmonic distortion is low. Scalability of the system and long term constraints of the system operations were however not taken care of.

Rao et al. [10] have implemented a smart EV charging station which operates with solar power, grid, and battery to offer indefinite charging. This will enable the system to alternate between energy sources to make sure that when the sun rays are minimal, the system does not stop functioning. Experimentally, the stability of properties of voltage and current was experimented upon. However, the article did not analyze the economic feasibility or the problem of the mass implementation.

Alkahtani et al. [11] offered a hybrid EV charging infrastructure that uses renewable energy sources (photovoltaic panels, wind turbines, and battery storage), which is smartly managed by applications. The grid system reduced grid dependency by over 30% and optimized energy consumption through smart charging. Also, blockchain-based payment systems reduce operational costs. Nevertheless, the paper did not provide an in-depth discussion of scalability and implementation complexity.

Irmas et al. [12] tested the optimal hybrid power plant configurations of solar photovoltaic systems, wind turbines, and battery storage to support EV charging demand. The experiment showed that hybrid systems save significant energy and improve load control compared to PV-only systems. Uncertainty analysis and cost modeling were also considered. Nevertheless, additional studies are needed to improve the precision of charging-demand predictions.

The strategy is the scheduling of hybrid energy storage charging in EV charging stations, which Erdogan and Hassen [13] proposed to optimize the scheduling of the charging process in EV charging stations. By utilizing the use of photovoltaic energy and by minimizing grid electricity use, the system benefits greatly. The experimental results showed a 12.13% decrease in overall grid energy expenses with accurate PV power forecasting. Nevertheless, these papers did not address operational issues or the prediction of uncertainties in large-scale systems.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

Ahmad and Thirumarai-Chelvan [14] suggested a hybrid control scheme, which involved the use of both proportional-integral control and deep reinforcement learning to charge several EVs' batteries simultaneously. Parameters which were optimized by the deep Q-network algorithm included voltage, current, and battery state of charge. The findings showed increased charging efficiency and improved voltage stability. However, the computational complexity and the feasibility of real-world implementation are not the topics that the paper has been concerned with.

The study by Samy and Barakat [15] focused on comparing the algorithms of multi-objective optimization in relation to charging the hybrid electric vehicles of photovoltaic, wind, and battery storage. Sustainability and reliability optimization algorithms, including NSGA-II, NSGA-III, and MOEA/D, were tested. The findings indicated that NSGA-II had high convergence performance. The limitations and the practical implementation difficulties were not stated in more detail, though.

According to a study in [16], an energy management system of a hybrid solar-biogas-based EV charging station was proposed. The algorithm maximized the use of renewable energy and reduced electric expenses by 74.67 percent compared to the traditional tariff. Also, greenhouse gas emissions were minimized by incorporating renewable energy. Nevertheless, the experiment did not assess the system's reliability under changing environmental conditions or its long-term performance.

The hybrid EV charging system introduced by Pawar and Bhargava [17] incorporates solar, wind, and flywheel energy storage, along with genetic algorithm-based power management. The suggested solution increased energy consumption efficiency by about 10 percent and operational expenses by 15 percent. Stable power delivery was achieved through dynamic load balancing. Nevertheless, the paper has not discussed the issue of hardware implementation and scalability of the optimization algorithm.

According to Shu et al. [18], HOMER Pro was used to model a hybrid microgrid combining photovoltaic systems, battery storage, and EV charging stations. The system reduces the net present cost while maximizing the use of renewable energy across different charging demand conditions. A sensitivity study examined the effects of variations in load and electricity prices. Nevertheless, restrictions associated with actual implementations were not thoroughly examined.

Khan et al. [19] proposed an independent-grid hybrid renewable system comprising solar photovoltaic panels, wind turbines, natural gas, and battery storage to charge electric vehicles at Malaysian EV charging stations. The techno-economic analysis was conducted to determine the best arrangement for a reliable energy supply. The hybrid system was more sustainable and performance-wise. Nevertheless, the study did not discuss scalability or infrastructure deployment issues.

To maximize energy use and minimize operational costs, Iskandar et al. [20] suggested that a hybrid photovoltaic-grid power system be offered at public EV charging stations. The combination of solar energy and grid electricity ensured a continuous power supply and offered environmental benefits. The system favored the creation of sustainable EV charging systems. Nonetheless, the research made a cursory reference to the problem of urban implementation without a specific analysis.

literature survey table

Various research works have been performed on different system architecture, ways of integrating renewable energy, power electronic design, and smart approaches to energy management. The literature under analysis shows the development of traditional grid-based charging systems in the direction of innovative hybrid ones that may include solar, wind, energy storage, and new control algorithms. The contributions, methodology, and limitations of the significant studies are thoroughly discussed in a literature review in Table I

Table 1: COMPARATIVE ANALYSIS OF HYBRID EV CHARGING SYSTEMS

Ref	Citation (Year)	Study Focus / Objective	Methods / Approach	Key Findings	Limitations
[1]	Cheikh et al. (2024)	Hybrid PV–Battery–Grid system for EV	MPPT-based PV system with battery storage and	Improved energy distribution and	Scalability and economic

		charging stations	grid integration	reduced fossil fuel dependency	feasibility were not discussed
[2]	Waheed et al. (2025)	Design of a 4 kW solar hybrid EV charging station	MATLAB and PVsyst simulation	Annual generation of 7,635.3 kWh and the capability to charge multiple EVs	MPPT limitations under partial shading
[3]	Vidyasagar et al. (2025)	Solar–wind hybrid EV charging station	MATLAB/Simulink modeling	Improved reliability and continuous energy supply	No real-world deployment analysis
[4]	Yadav et al. (2023)	Grid-connected solar–wind hybrid EV charging station	MPPT and OPAL-RT real-time simulation	Reduced reliance on conventional energy sources	Integration challenges were not discussed
[5]	Baccouche et al. (2024)	Hybrid PV–Battery–Fuel cell EV charging system	High-frequency inverter and boost converter	Improved power transmission efficiency	Lack of economic and implementation analysis
[6]	Singla et al. (2024)	Solar power-based hybrid EV charging station	Simulation-based multi-mode charging system	Capable of charging 10–12 EVs and exporting surplus energy	Possible grid overload during fast charging
[7]	IJSRST Study (2023)	Hybrid renewable EV charging station	Solar, wind, and storage with control algorithms	Reliable and sustainable EV charging	Scalability and cost evaluation are missing
[8]	Suchithra & Sadanandam (2025)	DER-based EV charging station with FOPID control	Fractional-order PID controller with DC bus architecture	Improved voltage regulation and reliability	Practical implementation not evaluated
[9]	Kumar & Rajan (2024)	Hybrid PV–Wind EV charging system with advanced control	Modified Zeta converter and SSOA-based fuzzy MPPT	Converter efficiency of 93.04% with low THD	Real-world validation limited
[10]	Rao et al. (2023)	Intelligent hybrid EV charging station	Solar-grid system with battery storage	Automatic energy source switching for reliability	Economic feasibility was not analyzed
[11]	Alkahtani et al. (2025)	Smart hybrid renewable EV charging infrastructure	Solar, wind, battery with a smart app and blockchain	Reduced grid dependency by >30%	Scalability and system complexity were not addressed
[12]	Irmas et al. (2024)	Optimal hybrid power plant for EV charging demand	Hybrid PV–Wind–Battery cost modeling	Lower energy cost compared to PV-only systems	Uncertainty in EV load estimation
[13]	Erdogan & Hassen (2023)	Charging scheduling using hybrid energy storage	PV forecasting and optimization scheduling	12.13% reduction in grid energy cost	Forecasting uncertainties not discussed
[14]	Ahmad & Thirumarai-Chelvan (2024)	Multi-battery EV charging control	PI control combined with deep reinforcement learning	Improved charging efficiency and voltage stability	Computational complexity not analyzed

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

[15]	Samy & Barakat (2023)	Optimization algorithms for hybrid EV charging systems	NSGA-II, NSGA-III, and MOEA/D optimization	NSGA-II showed better convergence	Implementation challenges were not discussed
[16]	IEEE Access Study (2023)	Energy management for solar–biogas EV charging station	MATLAB-based energy management algorithm	Energy cost reduced by 74.67%	Environmental variability was not analyzed
[17]	Gangadhar & Bhargava (2024)	Hybrid EV charging with GA optimization	Solar, wind, and flywheel storage with a genetic algorithm	10% efficiency improvement and 15% cost reduction	Hardware implementation not evaluated
[18]	Shu et al. (2025)	Hybrid microgrid EV charging system	HOMER Pro optimization	Reduced Net Present Cost and increased renewable use	Real-world deployment analysis is missing
[19]	Khan et al. (2024)	Grid-independent hybrid EV charging system	PV, wind, gas generator, and battery techno-economic analysis	Optimal hybrid configuration identified	Scalability challenges were not discussed
[20]	Iskandar et al. (2024)	Hybrid PV–grid EV charging station	PV-grid integration modeling	Reduced operational cost and environmental impact	Urban implementation challenges are briefly discussed

IV. RESEARCH GAP

Although there have been tremendous improvements in the hybrid based renewable energy EV charging systems, there are still gaps in research. The available literature addresses most of the simulation-based validation and little implementation on the real world. Also, the large-scale deployment issues, infrastructure needs and long-term operational performance have not been appropriately researched. In most studies, economic feasibility and lifecycle cost analysis have not been adequately studied. These gaps indicate the necessity to have scalable, cost-effective and realistically deployable hybrid EV charging infrastructures.

V. COMPARATIVE ANALYSIS OF EXISTING HYBRID EV CHARGING SYSTEMS

A. Comparison of System Architectures

The hybrid electric vehicle (EV) charging infrastructure can be constructed with a variety of system architecture in accordance with the incorporation of renewable power sources, storage technologies, and grid connectivity. The most common ones are photovoltaic-battery-grid, solar-wind hybrid, renewable microgrid-based charging stations, as well as the systems that include fuel cells or other backup power sources. Each architecture has got its own benefits in terms of reliability, energy efficiency, scalability and cost of operation. Infrastructure conditions, charging demand profiles, and resource availability are some of the key factors that determine the type of architecture to be used.

One of such arrangements is photovoltaic-battery-grid systems, which are popular due to the availability of solar energy and the reduction of the photovoltaic panel prices. Under this configuration, the solar PV panels produce electricity that can be used to supply the EV charging stations or stored in battery energy storage systems, with the grid backing up renewable production when they are less than required. Other architectures, like solar-wind hybrid systems or renewable microgrid-based charging stations, are even more reliable with the need to combine several energy sources and allow unbiased management of the energy. Other systems also incorporate sources of backup power like fuel cells or biogas generators to ensure the continued operation in the case of a longer period of renewable energy unavailability. Such solutions, however, can raise the cost and complexity of the system.

B. Comparison of Energy Management Techniques

Management methods in energy management are required to provide the best performance of the hybrid electric vehicle (EV) charging systems through the coordination of renewable energy sources, energy storage units and the grid. These methods guarantee effective use of energy, the reliability of the charge, and minimise the cost of operation. Among the literature, multiple strategies have been suggested, such as rule-based control, optimization- based and artificial intelligence-based strategies. The choice of a suitable strategy will be determined by the complexity of the system, the ability to compute and the balanced description between the cost-effectiveness and the use of renewable energy.

The simplicity and poor computational ability are the reason why rule-based control strategies are so prevalent, where users provide the set of rules and EV charging is prioritized to renewable energy, and batteries and the grid represent secondary options. On the other hand, the optimization techniques such as genetic algorithms, particle swarm optimization and linear programming are applied in order to achieve the best power allocation which will cut costs or utilize the renewable energy to its full extent. The methods of higher order implement the AI models, including neural networks, fuzzy logic and reinforcement learning, and adapt to the changing conditions and predict the energy demand/generation. Smart grid and blockchain solutions are also combined to use as a means of safe energy transactions, decentralization, and real-time monitoring by new solutions to make the hybrid EV charging infrastructure more efficient and flexible.

C. Performance Metrics for EV Charging Systems

Measuring the performance of hybrid EV charging systems should have proper measures of performance that will capture efficiency, reliability, sustainability and economics of the system. The major indicators that are popular in research encompass the energy efficiency, the use of renewable energy, system reliability, and its economic performance. Energy efficiency is a fraction of the useful energy provided to EVs as compared to the total energy produced or consumed in the system. The increased efficiency means that renewable resources are better used and the energy lost in the conversion, storage, and transmission processes reduced.

Another significant measure that will be important is the use of renewable energy; it is the ratio of all energy provided to renewable energy, thus indicating the extent of sustainability of the charging infrastructure. The financial viability of hybrid charging systems is determined by economic metrics, including the installation and the operational costs and the net present value, and the levelized cost of energy. Moreover, there are reliability and power quality indicators such as voltage stability, harmonic distortion, and load balancing, which guarantee the continuous and safe charging operation. The ecological advantage of the introduction of renewable energy during EV charging can also be evaluated with the help of environmental indicators, including carbon emissions reduction. All in all, these performance indicators facilitate holistic comparative studies and assist in the determination of efficient, reliable and sustainable configurations of hybrid EV charging infrastructures.

VI. FUTURE RESEARCH DIRECTIONS

A. Artificial Intelligence for Energy Management

The demand of EV charging, generation of renewable energy, and change in electricity prices can be predicted using machine learning (ML) algorithms. Such predictions enable the energy management systems to streamline power distribution between renewable sources, storage systems and grid electricity. Real-time load scheduling and charging prioritization can also be empowered by deep learning, reinforcement learning and neural network based controllers. Future studies ought to be directed at creating strong AI models that will be able to manage dynamic system conditions without being computationally complex.

B. Smart Grid Integration and Demand Response

This is because integration of hybrid electric vehicle (EV) charging infrastructure with smart grid infrastructure provides the opportunities to enhance grid stability and energy management. Smart grids provide the opportunity to

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 8, March 2026
Impact Factor: 8.2

create a two-way communication between charging facilities, power suppliers and the owners of EVs, to monitor and control the consumption of energy in real-time. Demand response programs are able to shift the EV charging loads to off-peak times, which would decrease grid congestion, and enhance energy efficiency. Moreover, smart grid technologies may support the use of dynamic pricing schemes promoting the use of energy to be very efficient. Further studies on this topic ought to investigate the advanced communication protocols, decentralized control approaches, and real-time monitoring systems to improve the integration of smart grids.

C. Advanced Energy Storage Technologies

Storage energy technologies are needed to match the renewable energy production with EV charging. Even though lithium-ion batteries are common in charging system of hybrid EV vehicles, new storage models, including solid-state batteries, hydrogen storage systems, and hybrid energy storage systems, are promising substitutes. Supercapacitors and flywheel systems have the ability to give a quick response to rapid variations in loads which will enhance the stability of the system and power quality. There should be research on high efficiency long-lasting and cost-effective energy storage, as this would help in large-scale hybrid charging infrastructure.

D. Sustainable and Scalable Charging Infrastructure

Since the electric vehicles (EVs) are quickly becoming popular, EV charging infrastructure in the future has to be scalable, reliable and environmentally friendly. Hybrid charging stations must be made in such a way that they can accommodate high-power fast charging and at the same time effectively manage their energy. Modular and distributed charging architecture can be developed to support the rising EV adoption without necessarily overloading the power grid that is already in place. Besides that, the combination of renewable energy microgrids and EV charging infrastructure can be used to promote energy independency and resiliency. The upcoming study must aim at creating scalable charging networks, better infrastructure planning, and creating standardized technologies that can be used to enable large-scale EVs.

VII. CONCLUSION

The adoption of hybrid-powered EV charging systems has become a viable solution towards coming up with reliable and sustainable electric vehicle charging infrastructure. Combining sources of renewable energy, including solar energy and wind power, with energy storage technologies and enhanced power management systems hybrid charging stations will be able to avoid significant dependence on electricity generation based on fossil fuel sources. These systems make the system more energy-efficient, have a smaller environmental impact and make the EV charging services more reliable.

This review examined the different hybrid electric vehicle (EV) chargers architecture, methods of renewable energy integration, energy storage technologies, and power electronics applied in EV charging facilities. A comparative analysis made several system arrangements and energy management strategies that enhance the efficiency of charging and the use of renewable energy. It was found that several challenges and gaps in the research existed, and they included renewable energy intermittency, problems with scalability, economic viability, and linkage to smart grid technologies.

Future studies are recommended to concentrate on smart energy management systems, novel optimization algorithms, and strategies of large-scale implementation of hybrid EV charging systems. Combining artificial intelligence, smart grid-based technologies, and more efficient energy storage systems will also improve the functionality and viability of EV charging networks. The development of hybrid-powered EV charge systems is another significant technological pathway to clean and sustainable transportation in the world.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 8, March 2026 Impact Factor: 8.2

REFERENCES

[1] G. Cheikh, C.-G. Haba, and H. A. Bentounes, "Study of a Hybrid System (PV-Battery-Grid) for Electric Vehicle Charging Stations," Oct. 2024, doi: 10.1109/epei63510.2024.10758138.

[2] A. Waheed, M. Anjum, and W. Arshad, "Design and MATLAB Simulation of a 4 kW Solar Hybrid EV Charging Station," Sep. 2025, doi: 10.63056/acad. 004.03.0770.

[3] B. Vidyasagar, T. Yalka, and A. S. Siddhartha, "Design of Solar-Wind Hybrid Electric Vehicle Charging Station Using Matlab," International Journal of Environmental Sciences, Aug. 2025, doi: 10.64252/89c9st91.

[4] R. Yadav, M. K. Maurya, and G. Mv, "Implementation of a Solar-Wind Hybrid Charging Station for Electric Vehicles," Jul. 2023, doi: 10.1109/pesgm52003.2023.10252756.

[5] G. Baccouche, M. H. Chehab, and C. B. Salah, "Hybrid PVP/Battery/Fuel Cell Wireless Charging Stations Using High-Frequency Optimized Inverter Technology for Electric Vehicles," Energies, Jul. 2024, doi: 10.3390/en17143470.

[6] P. Singla, S. Boora, P. Singhal, et al., "Design and Simulation of 4 kW Solar Power-Based Hybrid EV Charging Station," Scientific Reports, Mar. 2024, doi: 10.1038/s41598-024-56833-5.

[7] "Efficient Integration of Renewable Energy for Electric Vehicle Charging: A Hybrid System Approach," International Journal of Scientific Research in Science and Technology, Jun. 2023, doi: 10.32628/ijsrst523103151.

[8] B. Suchithra and P. Sadanandam, "Fractional-Order PID Controlled DER-Based EV Charging Station with Seamless Grid Connection," Sep. 2025, doi: 10.64771/jsetms.2025.v02.i09.pp1-16.

[9] R. T. Kumar and C. C. A. Rajan, "Optimized Hybrid Renewable Energy System for Sustainable Electric Vehicle Charging: Integration of Photovoltaic and Wind Power with Advanced Control Strategies," IEEE Access, Jan. 2024, doi: 10.1109/access. 2024.3521515.

[10] P. S. Rao, R. Dash, and R. Jena, "Synergistic Energy Utilization for Intelligent EV Charging Stations via Hybrid Sources," Nov. 2023, doi: 10.1109/rasse60029.2023.10363566.

[11] A. A. Alkahtani, A. Q. Al-Shetwi, M. A. El-Hameed, et al., "Hybrid Renewable Energy and Smart App-Based Management for Efficient and Sustainable EV Charging Infrastructure," International Journal of Energy Research, Jan. 2025, doi: 10.1155/er/5872792.

[12] C. Irmas, K. Brunik, and C. E. Clark, "Optimal Hybrid Power Plants for Electric Vehicle Charging Demand," Journal of Physics: Conference Series, Jun. 2024, doi: 10.1088/1742-6596/2767/8/082015.

[13] G. Erdogan and W. F. Hassen, "Charging Scheduling of Hybrid Energy Storage Systems for EV Charging Stations," Energies, Sep. 2023, doi: 10.3390/en16186656.

[14] A. Ahmad and I. Thirumarai-Chelvan, "Hybrid Control Scheme for More Efficient Charging of Two Electric Vehicle Batteries Simultaneously," Aug. 2024, doi: 10.1109/ccece59415.2024.10667156.

[15] M. M. Samy and S. Barakat, "Comprehensive Analysis of Multi-Objective Optimization Algorithms for Sustainable Hybrid Electric Vehicle Charging Systems," Mathematics, Apr. 2023, doi: 10.3390/math11071741.

[16] "Energy Management System for Hybrid Renewable Energy-Based Electric Vehicle Charging Station," IEEE Access, Jan. 2023, doi: 10.1109/access. 2023.3259232.

[17] P. S. Gangadhar and A. Bhargava, "Genetic Algorithm-Based Strategies for Enhanced Power Management in Hybrid Charging Systems," Smart Moves Journal IJOSCIENCE, Jun. 2024, doi: 10.24113/ijoscience.v10i6.524.

[18] S. Shu, F. Yang, and J. Lu, "Modelling of Hybrid Microgrid with EV Charging Station Using HOMER Pro," IEEE Region 10 Symposium (TENSYMP), Jul. 2025, doi: 10.1109/tensymp63728.2025.11144935.

[19] F. A. Khan, S. Mekhilef, V. K. Ramachandaramurthy, et al., "Design and Development of Grid Independent Integrated Energy System for Electric Vehicle Charging Stations at Different Locations in Malaysia," Energy, May 2024, doi: 10.1016/j.energy.2024.131686.

[20] H. R. Iskandar, E. Taryana, and A. Daelami, "Modelling of a Hybrid Photovoltaic-Grid Source on Public Electric Vehicle Charging Station (PEVCS)," Aug. 2024, doi: 10.59613/cf20tt53