

PV-Based-Off-Grid-Charging-Station-for-Electric-Vehicle: A Review

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Abstract –

The rapid advancement of electric mobility has increased the demand for reliable and sustainable charging solutions. This project presents a PV-based off-grid charging station for electric vehicles, designed to operate independently of conventional grid infrastructure while ensuring continuous and eco-friendly power availability. The system utilizes a solar photovoltaic (PV) array as the primary energy source, supported by a solar charge controller, battery storage, inverter module, voltage sensing unit, and optional grid backup. Solar energy harvested during the day is stored in a battery and later utilized for EV charging or operating AC loads through an inverter. Real-time monitoring of voltage and system parameters ensures efficient power management and protects the battery from overcharging or deep discharge. The proposed model demonstrates stable performance under varying solar conditions and highlights the feasibility of deploying renewable-based charging solutions in rural, remote, or grid-scarce regions. This hardware prototype contributes toward reducing carbon emissions, lowering dependency on fossil fuels, and promoting clean energy adoption in the transportation sector.

Keywords: Solar Photovoltaic (PV) System, Off-Grid Charging, Electric Vehicle (EV), Battery Energy Storage, Inverter Module etc.

I. INTRODUCTION

The global transition toward sustainable energy systems and green transportation has accelerated the demand for reliable, eco-friendly, and cost-effective charging solutions for electric vehicles (EVs). As EV adoption grows, the need for widespread charging infrastructure becomes increasingly critical, particularly in regions where grid connectivity is weak, unreliable, or completely unavailable. Traditional EV charging stations rely heavily on the electrical grid, which not only increases operational costs but also contributes to higher carbon emissions if the grid is powered by fossil fuels. In this context, solar photovoltaic (PV) technology emerges as one of the most promising renewable energy alternatives due to its abundance, low maintenance, and environmental benefits. A PV-based off-grid charging station offers a self-sustaining solution that can function independently while ensuring uninterrupted power supply for EV charging.

The concept of an off-grid solar charging station revolves around capturing energy from the sun using solar panels, regulating this energy through a solar charge controller, storing it in a battery bank, and converting it into usable AC power through an inverter module. This stored energy can be utilized at any time, enabling EV charging even during non-sunny hours or at night. The integration of components such as voltage sensors, LCD displays, and protective circuitry ensures that the system operates with high safety, efficiency, and performance reliability. Additionally, the inclusion of an optional grid backup enhances system flexibility, ensuring that the charging station can function during extended cloudy periods or high-load conditions.

The development of a PV-based off-grid charging station holds great significance for both urban and rural applications. In rural or remote areas where grid access is limited or absent, such systems provide a practical and sustainable method for supporting electric mobility. For urban environments, they serve as a way to reduce peak demand on the grid and promote renewable energy usage. By decentralizing energy generation and reducing

dependency on traditional power infrastructure, solar-based charging stations contribute to improved energy security and long-term cost savings.

The hardware model designed in this project demonstrates the working principle and functionality of an off-grid solar charging station. It incorporates real-world components such as a solar panel, charge controller, deep-cycle battery, inverter module, and voltage monitoring system to simulate an actual charging station. The system has been engineered to manage energy distribution efficiently, maintain battery health, and provide stable AC output for EV charging. The monitoring system provides real-time data, allowing users to assess energy availability and performance.

Overall, the PV-based off-grid charging station represents an innovative and practical solution for addressing the challenges of charging infrastructure expansion, environmental sustainability, and energy accessibility. As the global energy landscape shifts toward renewable technologies, such systems play a vital role in supporting clean transportation and reducing dependence on fossil fuels. This project not only reinforces the potential of solar energy for EV applications but also serves as a foundation for future advancements in decentralized, green charging networks.

II. BEHIND RESEARCH

Fast charging as an indoor electric vehicle board is hindered by the cost of the electronic components needed to convert the electricity, which increases the overall cost of the electric car. However, built-in chargers cannot ensure fast EV charging due to the high cost of EV-related electronics and increasing the charging capacity of the car.

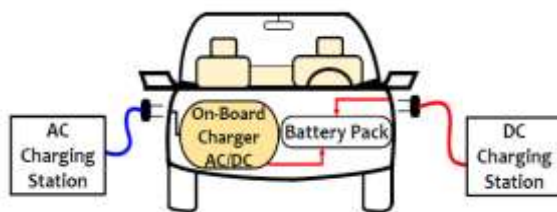


Fig.1. Hybrid EV Charging Station

To ensure faster charging of electric vehicles, external chargers are used that provide high direct current. It is worth noting that in external chargers, the entire conversion from AC/DC is done by an independent inverter. That is why it is important to increase the power of the converters to ensure faster charging of the car. The results of several published studies have been used in the design and development of efficient and reliable electric vehicle charging systems at electric vehicle charging stations.

Hybrid Power :

A hybrid power tool combines two energy sources to supply electricity efficiently. It is a system designed to generate power using multiple sources, ensuring reliability, efficiency, and low emissions at a minimal cost. In the proposed system, solar and wind energy are utilized for electricity generation. These renewable sources offer significant advantages over conventional power, providing a sustainable and cost-effective solution. The system requires minimal investment and can be installed anywhere without location constraints. By integrating solar and wind power, the hybrid system ensures continuous energy availability, making it an ideal choice for various applications.

In this proposed gadget, solar and wind power are employed to generate electricity. Sun and wind strength have distinct advantages as compared to all other unconventional electricity sources. Each power asset is required in all areas. It desires a low fee. There is no need to identify a specific area to put in this gadget.

Solar Power :

Solar energy is power generated by the sun's radiation, which is constantly and readily available on the earth. It is freely accessible, does not emit pollutants, has minimal upkeep expenses, and is cost-effective. However, it has difficulty producing power in bad weather conditions. Solar energy is more efficient than conventional sources, requiring an upfront investment but having a longer lifespan and lower emissions.

III. LITERATURE SURVEY

Alrubaie, A.J. (2023), survey charging modes, standards, and grid-integration challenges for EVs. The review compares wired, wireless and battery-swap approaches, highlights interoperability and safety standards, and stresses impacts on distribution networks. It finds that integration of distributed renewables (PV + storage) can mitigate grid stress but requires coordinated energy management, smart charging, and regulatory updates. The authors call for standardized communication protocols and economic models to make PV-coupled charging stations viable at scale.

Saraswathi, V.N. (2024), reviews charger topologies, power electronics, and standardization trends. The paper details AC/DC converter architectures, charging protocols (CHAdeMO, CCS), and safety/connectivity requirements. It emphasizes that EV chargers paired with onsite PV and BESS need advanced converters and grid-support functions (V2G/V2H). The review highlights research gaps in harmonics mitigation, bidirectional power flow integration, and cost-effective converter designs for small-scale PV-EV applications.

Borhani, A. (2024), examines PV + battery architectures for residential EV charging, focusing on optimization algorithms and control strategies. The study demonstrates that coordinated scheduling and storage dispatch reduce grid peak demand and charging costs. It also shows that even modest battery capacities significantly increase PV self-consumption when paired with predictive control under variable solar profiles. The paper recommends predictive weather/usage forecasting and adaptive EMS for reliable off-grid and grid-assisted charging.

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Pal, K. (2024) , surveys EMS strategies for fast-charging stations integrating PV and ESS. The review contrasts rule-based, optimization-based, and AI-driven controllers. Findings indicate optimization (MPC/GA) improves cost and battery life versus static heuristics, while hybrid schemes (rule + learning) offer robustness. The paper highlights the need to trade off charging speed, ESS cycling costs, and PV intermittency, recommending ESS sizing guidelines tied to local irradiance and traffic patterns.

Kumar, M. (2023), provide an overview of EV tech, charging infrastructure, and renewable integration. The review finds that PV and storage can reduce operational emissions of EVCS, but economic viability depends on location, incentives, and battery costs. Technical gaps include EMS design for multi-site coordination, fast charging compatibility with renewables, and lifecycle assessments accounting for ESS degradation. The authors recommend pilot deployments and standardized metrics for PV-EV system evaluation.

Bhutkar, G. (2024), reviews EMS implementations for EV charging hubs, comparing centralized vs. distributed control and scheduling algorithms. The work underscores importance of demand forecasting, priority rules for EVs, and seamless integration of onsite PV and backup grid. Case studies show EMS reduces peak loads and optimizes battery usage. The review highlights cybersecurity, communication standards, and need for real-time telemetry for resilience.

Tripathi, A.K. (2025), analyzes system-level challenges for embedding PV at EVCS: site layout, inverter sizing, ESS selection, and permitting. The review stresses that DC-coupled PV+ESS improves round-trip efficiency for charging, while AC-coupled systems offer retrofit flexibility. Economic modeling shows grid-export tariffs and time-of-use rates strongly influence payback. The paper calls for harmonized design tools and standardized testbeds to accelerate commercial rollouts.

Olano, J. (2025), research focusing on cost minimization, BESS degradation modeling, and scheduling under uncertainty. The review highlights that incorporating battery aging into EMS objective functions materially affects dispatch decisions and lifetime costs. Comparing methods, stochastic optimization and robust MPC perform best under uncertain arrival/solar conditions. The authors recommend combined economic + battery health optimization for sustainable EVCS operation.

Tamba II, J.S. (2025), addressing design, control, and techno-economic analyses. The review concludes that off-grid PV stations are feasible for low-throughput sites, while hybrid (PV+grid+ESS) suits urban fast-charging. Key technical needs include high-efficiency DC–DC/DC–AC converters, modular ESS, and predictive EMS integrating weather and traffic forecasts. The paper urges standardized benchmarking and life-cycle environmental assessments to validate long-term sustainability claims.

IV. BLOCK DIAGRAM

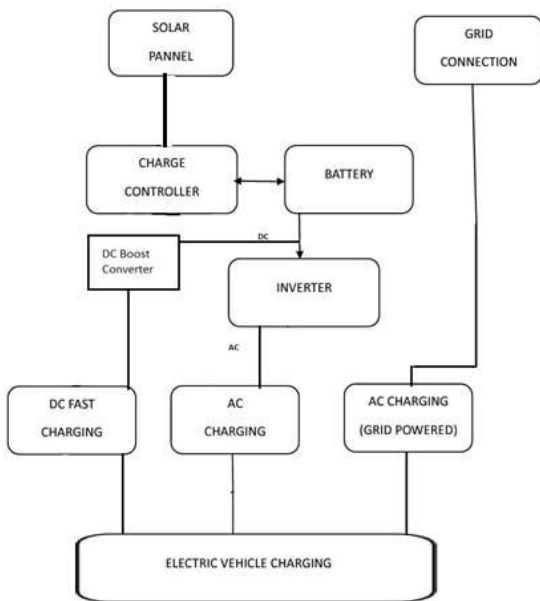


Fig.2. Block Diagram of system

V. PROJECT DESCRIPTION

- The system begins with a solar panel, which captures sunlight and converts it into DC electrical energy for charging and storage.
- This power is regulated by the solar charge controller, which prevents battery overcharging and manages optimal charging conditions.
- The battery stores the regulated DC energy, ensuring continuous EV charging even during night or low-sunlight periods.
- A DC boost converter is used to step up the DC voltage when higher voltage levels are required for DC fast charging.
- The boosted DC power is supplied directly to the DC fast charging unit, enabling quick charging of electric vehicles.
- The stored DC power from the battery is also fed into an inverter, which converts DC energy into AC power for AC charging loads.
- The AC charging unit supplies regulated AC output for standard EV charging modes.
- The system also includes a grid connection as an emergency or backup power source, enabling AC grid-powered charging when solar or battery energy is insufficient.
- All charging pathways—DC fast charging, AC charging, and AC grid charging—integrate into the final Electric Vehicle Charging output.

VI. 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 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.



VII. 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.

VIII. APPLICATION

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

IX. 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.

X. CONCLUSION

The proposed PV-based off-grid charging station is expected to demonstrate a reliable, sustainable, and cost-effective solution for electric vehicle charging. By integrating solar panels, a charge controller, battery storage, and an inverter system, the model ensures uninterrupted charging even in the absence of grid power. The inclusion of both DC fast charging and AC charging modes enhances flexibility and supports various EV requirements. The system utilizes renewable energy, reducing dependency on conventional electricity and minimizing environmental impact. Real-time monitoring and efficient energy management further improve system performance and battery life. Overall, the project is anticipated to validate the feasibility of solar-powered EV charging and promote cleaner, decentralized charging infrastructure for future mobility.

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