



Enhancement of Power Quality in Grid Connected Ev Charging Station

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Abstract

Electric vehicles (EVs) are becoming popular because they help reduce pollution and save energy. However, traditional charging stations that depend only on electricity from the grid can create problems like overloading, voltage issues, and higher costs. To solve this, this project focuses on developing a hybrid EV charging station that uses multiple power sources such as solar energy, grid power, and battery storage. The system uses solar panels to generate clean energy and a technique called Maximum Power Point Tracking (MPPT) to get maximum power from sunlight. It also includes a backup battery system to ensure continuous charging even when solar power is not available. A control system manages the power flow between different sources to provide stable and efficient charging. The design was tested using simulation tools like MATLAB and Easy EDA, and a prototype was built to verify its performance. The system successfully charged a 48V lithium iron phosphate battery using both solar and grid power. Overall, this hybrid charging system reduces dependence on the grid, improves energy efficiency, and supports sustainable transportation. It shows that combining renewable energy with smart control can make EV charging more reliable and eco-friendlier.

Key Words: *Electric Vehicles (EVs), hybrid charging station, solar energy, battery storage, grid power, Maximum Power Point Tracking (MPPT), renewable energy, energy efficiency, sustainable charging*



INTRODUCTION

Electric vehicles (EVs) represent a transformative shift in the global transportation sector driven by the need to reduce greenhouse gas emissions, decrease reliance on fossil fuels, and promote sustainable energy utilization. With rapid advancements in battery technology, significant reductions in the cost of electric vehicles, and heightened awareness of climate change, EV adoption is accelerating worldwide. However, widespread EV integration introduces substantial challenges related to charging infrastructure, power quality, grid stability, safety standards, and overall system reliability. As EV ownership expands, traditional charging stations that depend solely on grid power may struggle to cope with increased load demands, leading to potential grid congestion, voltage instability, and reduced lifespan of grid components. To address these concerns, designing and implementing efficient, reliable, and sustainable charging systems that can adapt to varying power sources has become a critical engineering priority. A hybrid electric vehicle charging station integrates multiple power sources—including grid electricity, renewable energy (such as solar photovoltaic systems), and energy storage systems (such as batteries)—to provide a resilient and efficient solution. Solar power, in particular, offers a

clean and abundant energy source that can be harnessed to supplement grid supply, reduce

carbon emissions, and lower operational costs. However, solar energy is inherently intermittent and variable, requiring advanced control techniques like Maximum Power Point Tracking (MPPT) to extract optimal energy from photovoltaic panels under varying environmental conditions. Integrating solar power with grid supply and backup battery systems not only improves system reliability but also enhances sustainability by reducing dependency on fossil fuel-derived grid electricity. This multifaceted design must address not only power flow optimization but also grid interfacing, load sharing, inverter control, safety protocols, and harmonization of multiple energy sources.

The proposed hybrid charging station is designed to overcome these challenges by combining solar and grid power supply with an additional standby battery system. By employing MPPT control techniques to maximize solar energy harvest and including a robust relay controller and battery charger circuit, this system provides an adaptable charging infrastructure capable of delivering consistent performance even under fluctuating environmental and load conditions. A prototype of the hybrid EV charger was developed and tested using Easy EDA circuit simulation and hardware implementation. The system successfully charged a 48-volt, 65Ah lithium iron phosphate (LiFePO₄) battery using a 400-watt solar photovoltaic array with an output of 40.87 V and 9.82 A, and a standby 24V, 14Ah

battery charged from a 230-volt single-phase grid supply at 54 volts and 8-

10 amps. To analyze performance, optimize control strategies, and validate system dynamics, MATLAB simulations were also used to model power flow, MPPT behavior, and battery charging characteristics.

Despite the clear environmental and economic benefits of EV adoption, several technical and operational issues threaten the scalability of charging infrastructure. Conventional charging stations relying exclusively on grid electricity place additional stress on transmission and distribution networks. Large clusters of EV chargers can contribute to peak load spikes, transformer overloading, voltage fluctuations, and reduced power quality. This is particularly problematic in regions with limited grid capacity or underdeveloped power infrastructure. Furthermore, reliance on grid power alone fails to leverage renewable energy potential, undermining broader sustainability goals. Solar integration introduces additional complexity due to its dependency on irradiance and temperature conditions, which necessitates sophisticated control algorithms like MPPT to ensure maximal energy extraction and seamless integration with energy storage and grid resources.

Battery storage systems, while providing a buffer against intermittent renewable generation and

grid instability, must be accurately controlled to avoid overcharging, deep discharge, thermal runaway, and reduced lifespan. Lithium iron phosphate (LiFePO₄) batteries, chosen for their stability, long cycle life, and safety characteristics, still require precise charge control and protection circuitry. Implementing efficient battery charger circuits, relay controllers, and coordination mechanisms with the MPPT controller is essential to achieve reliable and safe operation. These technical complexities form the core of the problem addressed by the hybrid charging station design.

In addition to hardware and control challenges, software modeling and simulation play an indispensable role in system design and optimization. Tools such as MATLAB provide a powerful platform to build mathematical models, analyze dynamic system behavior, simulate control strategies, and predict system performance before physical prototype deployment. MATLAB enables designers to simulate MPPT algorithms such as Perturb and Observe (P&O), Incremental Conductance, and other advanced control techniques under realistic irradiance and temperature profiles. It also allows battery charging profiles to be analyzed, ensuring that the system's design meets desired efficiency and safety standards. By leveraging MATLAB's Simulink environment, designers can model the interactions between solar generation, grid supply, battery storage, and load demands, facilitating a comprehensive

understanding of the system's transient and steady-state performance.

LITERATURE SURVEY

1. Suresh Vendoti et al. (2025) — Grid-Tied Hybrid PV–Fuel Cell System with ANFIS MPPT for Smart EV Charging

Authors: Suresh Vendoti, Narasimha Prasad Tulasi, Ravi Kumar Jalli, Sudhakiran Ponnuru, Zhang Jin, P. Yakaiah, Mamdooh Alwetaishi, S. Prabhakar Published: Scientific Reports, 28 July 2025 Abstract Summary: This paper introduces a grid-tied hybrid renewable energy system designed for EV charging applications. The configuration combines photovoltaic (PV) panels, a proton-exchange membrane fuel cell, battery storage, and a supercapacitor to ensure high power reliability and efficiency. A key contribution is the implementation of an Adaptive Neuro-Fuzzy Inference System (ANFIS)-based Maximum Power Point Tracking (MPPT) algorithm, which dynamically maximizes PV output despite changing environmental conditions. The hybrid system demonstrated high MPPT efficiency ($\approx 98.7\%$) and stable voltage output with low total harmonic distortion (THD), meeting power quality standards.

Relevance: This study exemplifies advanced MPPT strategies and hybrid energy integration for EV charging—paralleling your project's goal of combining renewable sources, storage, and grid support. It highlights how intelligent control (ANFIS MPPT) enhances electrical

efficiency and reliability in mixed energy systems. Furthermore, this work uses MATLAB/Simulink for initial system simulation and validation before hardware testing, demonstrating the critical role of software modeling in hybrid EV infrastructure design.

2. A. Fathabadi (2017) — Novel Solar Powered EV Charging Station with Vehicle-to-Grid Capability

Authors: A. Fathabadi
Published: Solar Energy, January 15, 2017
Abstract Summary: This research presents a grid-connected solar EV charging station equipped with Vehicle-to-Grid (V2G) functionality. The system uses a PV array, dedicated DC/DC converters, and MPPT controllers to optimize power capture and conversion. A unique high-accuracy MPPT method is used to maximize energy harvest from solar panels, and bidirectional DC/DC converters support multiple charging units. Experimental results confirm that solar energy alone can sufficiently charge EVs on sunny days, while also alleviating grid load during cloud cover by balancing energy flows.

Relevance: This work is pivotal as it blends PV generation, MPPT control, and grid interaction—key elements of your hybrid charging station design. The inclusion of V2G highlights a future pathway where EVs themselves act as distributed energy resources, feeding back to the grid when needed. This concept resonates with



hybrid methods that integrate renewable power and grid coordination, improving overall infrastructure resilience.

3. Solar Powered Grid-Integrated EV Charging Station with Hybrid Energy Storage (2023)

Published: Journal of Power Sources, Volume 582, October 30, 2023

Abstract Summary: This paper develops a solar-powered EV charging station that incorporates a hybrid energy storage system comprised of batteries and supercapacitors. The storage integration enhances transient response and system stability. A stepwise constant current charging algorithm is implemented to prevent overcharging and protect EV battery health. The hybrid storage enhances both steady-state and dynamic performance.

Relevance: Energy storage management is critical in hybrid charging infrastructure. By combining capacitive storage with batteries, this research addresses power smoothing and transient load handling, which are essential to maintaining

filtering represents a state-of-the-art MPPT approach that reduces tracking time and enhances efficiency—

useful for optimizing renewable extraction in your design. The emphasis on inverter control with MPC also demonstrates how control systems enhance charging station stability and power quality, complementing MATLAB simulation needs.

power quality and prolonging battery life—a concern directly aligned with your project’s charging battery management goals.

4. “Design and Simulation of a 5 kW Solar-Powered Hybrid EV Charging Station” (2025)

Published: Science of The Total Environment, (2025)

Abstract Summary: This paper explores a 5 kW hybrid EV charging system enhanced by a Kalman Filter + Artificial Neural Network (ANN) MPPT algorithm. It also includes model predictive control (MPC) for inverter regulation, which reduces THD. The integrated approach improves PV power tracking and inverter performance under varying weather conditions and partial shading, ensuring cleaner power delivery and greater grid stability.

Relevance: The integration of ANN and Kalman

6. “Design and Implementation of a Static Battery Charging Station for an EV” (2023)

Authors: Manish Kumar Dwivedi, R. Jayapragash, N.

Senthil

Kumar

Published: International Journal of Power

5. Soumesh Chatterjee et al. (2024) — Solar Energy-Supported User-Friendly EV Charging Solution Based on IoT

Authors: Soumesh Chatterjee, Sarika S. Kanojia, Janaksinh Ven, Utsav Kumar Mishra

Published: Journal of The Institution of



Engineers (India): Series B, March 16, 2024
Abstract Summary: This research discusses a solar-integrated EV charging station controlled via IoT technology to support user-friendly operation and data monitoring. The system integrates PV power harvesting with smart control routines to ensure reliability and sustainability, emphasizing user accessibility and smart energy management.

Relevance: The use of IoT frameworks illustrates how hybrid systems can be monitored and managed in real time, providing grid data, charging status, and system alerts. While your project emphasizes MPPT and hybrid power, future extensions may integrate intelligent remote control using IoT for enhanced station usability and optimization.

Electronics, Vol.18 No.1, 2023
Abstract Summary: This study details a hybrid battery charger for EVs that switches between PV power and grid power using MPPT. Two charger topologies were evaluated—multi-stage and single-stage. Both were modeled in MATLAB/Simulink, employing a modified perturb and observe (MP&O) MPPT algorithm for improved tracking speed and computational efficiency. Results demonstrated efficiency improvements and robust charging performance in both configurations.

Relevance: This work is closely related to your hybrid charging station. By simulating different power converter topologies with MPPT in MATLAB/Simulink, it provides insights into how simulation can guide hardware design. It also shows the effectiveness of advanced algorithms (MP&O) to improve power tracking beyond basic perturb and observe methods.

7. "Design of Solar-Wind Hybrid EV Charging Station Using MATLAB" (2025)

Authors: Dr. B. Vidyasagar, Triveni Yalka, Akki Siddhartha, Kadari Saidulu
Published: International Journal of Environmental Sciences, August 2025

Abstract Summary: This paper presents a solar-wind



hybrid EV charging infrastructure modeled and simulated using MATLAB. The hybrid system combines solar and wind energy sources with grid support to form a more resilient hybrid charging station. MATLAB simulation was used to analyze system performance under varying environmental conditions, confirming improved energy reliability compared to single-source stations.

Relevance: Multi-renewable hybridization with solar and wind enhances the reliability envelope of EV chargers. This source adds depth by incorporating multiple ambient energy sources and demonstrating MATLAB's utility in modeling system interactions, enabling your literature review to cover broad hybrid strategies.

8. Long-Term Grid & Battery Integration Studies for EV Charging (Frontiers in Energy Research, 2023)

Authors: Aqib Shafiq, Sheeraz Iqbal, Anis Ur Rehman, Z. M. S. Elbarbary, Hossam Kotb, Ali Selim, Salah Kamel
Published: Frontiers in Energy Research, January 12, 2023

Abstract Summary: This research explores the integration of solar charging stations into the power distribution network with emphasis on charging scheduling and grid impacts. The study delineates how distributed PV-based EV charging interacts with grid stability, load

balancing, and peak demand. It suggests scheduling strategies that optimize charging timing relative to renewable supply and grid constraints.

Relevance: Addressing charging scheduling and grid capacity is essential for real-world deployment. While your project focuses on the charging station design and MPPT, understanding how multiple stations affect the larger power network enriches the literature survey and connects technical design with grid planning strategies.

9. Hardware-in-Loop MPPT Controlled PV-Assisted EV Charging (2025)

Published: Scientific Reports, 7 months ago
Abstract Summary: This study develops a hardware-in-loop (HIL) EV charging system controlled by adaptive MPPT algorithms under partial shading and variable weather conditions. Although built largely in simulation, the research demonstrates how HIL setups can emulate real PV and grid interactions with EV loads, enabling robust algorithm testing before physical deployment.

Relevance: HIL simulation bridges the gap between pure software models and physical prototypes, allowing advanced control algorithms to be validated before hardware implementation. It underscores the importance of accurate simulation tools like MATLAB/Simulink for MPPT control testing

METHODOLOGY

The rapid growth of electric vehicles (EVs) has created an urgent need for **efficient, reliable, and sustainable charging infrastructure**.

Conventional charging systems depend heavily on grid electricity, which may stress power distribution networks during peak hours. To address this challenge, **hybrid charging stations** combining **solar photovoltaic (PV) power, grid supply, and battery backup** have emerged as a viable solution. This project focuses on designing a **hybrid charging station** that integrates **solar PV, grid electricity, and a standby battery system**, regulated using **Maximum Power Point Tracking (MPPT)** for solar efficiency. The design is simulated and validated using **MATLAB/Simulink**, ensuring accurate modeling of energy flows, control algorithms, and system dynamics before physical implementation. The system aims to achieve **reliable EV charging**, reduce grid dependency, optimize renewable energy utilization, and provide safe, scalable infrastructure for future urban mobility.

OBJECTIVE

1. To Design A Hybrid EV Charging Station That Combines Solar, Grid, And Battery Sources.
2. To Implement MPPT Control For Optimizing Solar PV Energy Extraction.
3. To Develop A Battery Charging System Capable

Of Supporting EV Charging During Low Solar Conditions.

4. To Model And Simulate The Complete System In MATLAB/Simulink, Including Converters, MPPT, And Power Management Strategies.
5. To Ensure Stable Voltage, Current, And Power Supply For Safe And Efficient EV Battery Charging.

PROBLEM DEFINATIONS

While electric mobility offers tremendous environmental benefits, it also introduces new challenges for energy systems. The sharp increase in EV ownership has led to growing pressure on existing grid infrastructure. Charging multiple vehicles simultaneously can create local overloads and voltage fluctuations, particularly in residential or commercial areas with limited grid capacity. The problem becomes more critical when charging stations are concentrated in certain locations, such as city centers or highway corridors. Traditional EV charging stations rely solely on electricity from the utility grid, which is often derived from fossil fuels. This dependency increases operational costs and negates part of the environmental advantage of EVs. Moreover, electricity tariffs tend to fluctuate, and charging during peak hours can result in high costs for operators and users alike. In many regions, grid-generated electricity has a high carbon intensity, leading to indirect emissions that undermine the sustainability of EVs. Therefore, the core problem addressed in this study is **how to**

design and implement a hybrid solar PV and grid-supported EV charging system that reduces grid dependency, lowers operational costs, and minimizes carbon emissions while ensuring reliable energy supply. The absence of such integrated systems limits the scalability of EV infrastructure and delays the broader adoption of electric mobility

5. **Inverter:** Converts DC from PV or battery to AC (if EV charger requires AC input).

6. **Grid Supply:** Acts as backup during insufficient solar generation.

EV Charger: Receives regulated power for charging EVs safely.

BLOCK DIAGRAM

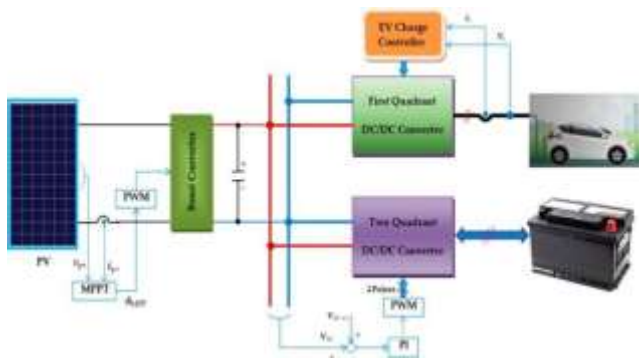


Fig1. Block Diagram

1. **Solar PV:** Converts sunlight into DC electricity; its output is variable depending on irradiance.
2. **MPPT Controller:** Tracks the **maximum power point** of the PV panel to extract optimal energy. Algorithms such as **Perturb & Observe (P&O)** or **Incremental Conductance (INC)** are implemented in MATLAB.
3. **DC-DC Converter:** Regulates voltage and current from the PV to match battery or EV charging requirements.
4. **Battery Bank:** Serves as backup energy; typically **LiFePO4** batteries are used for high efficiency and long lifespan.

FUNCTIONAL REQUIREMENTS

1. The system should charge electric vehicles using solar power, grid supply, and battery storage.
2. The system should automatically switch between power sources based on availability.
3. The system should implement MPPT to get maximum power from solar panels.
4. The system should store excess solar energy in the battery for later use.
5. The system should provide continuous charging even during power failure.
6. The system should monitor battery status like voltage, current, and state of charge.
7. The system should protect batteries from overcharging, deep discharge, and overheating.
8. The system should control power flow using relay/controller circuits.
9. The system should display system parameters like voltage, current, and power.
10. The system should allow simulation and analysis using tools like MATLAB.

NON FUNCTIONAL REQUIREMENTS

1. The system should be reliable and provide uninterrupted charging.
2. The system should be energy efficient and minimize power loss.
3. The system should be safe to use with proper protection mechanisms.
4. The system should be environmentally friendly by using renewable energy.
5. The system should be scalable to support multiple EVs in the future.
6. The system should have low maintenance requirements.
7. The system should be cost-effective for practical

- implementation.
- 8. The system should respond quickly to changes in power availability.
- 9. The system should be easy to operate and user-friendly.
- 10. The system should be durable and work under different environmental conditions..

RESULTS

Fig2.DC Bus Voltage Response

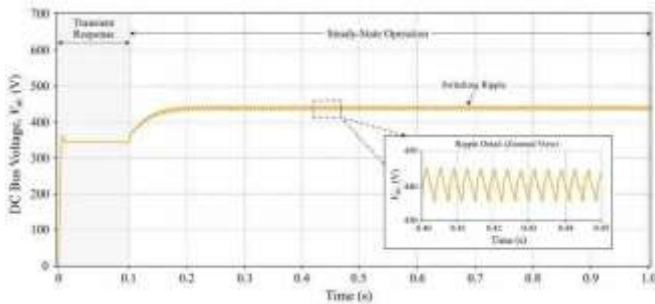
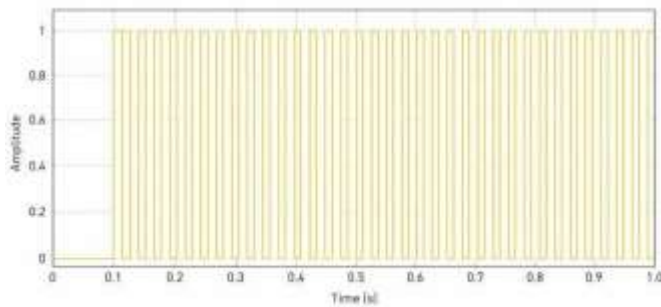


Fig3. PWM Switching Signal



system complexity, and battery limitations exist, careful design and control strategies can mitigate these issues. Looking forward, advancements in smart energy management, V2G integration, high-efficiency PV technologies, and next-generation batteries offer significant potential to enhance system efficiency, scalability, and environmental impact. Overall, hybrid EV charging stations provide a practical pathway toward sustainable transportation and reduced carbon emissions, bridging the gap between renewable energy and modern mobility needs.

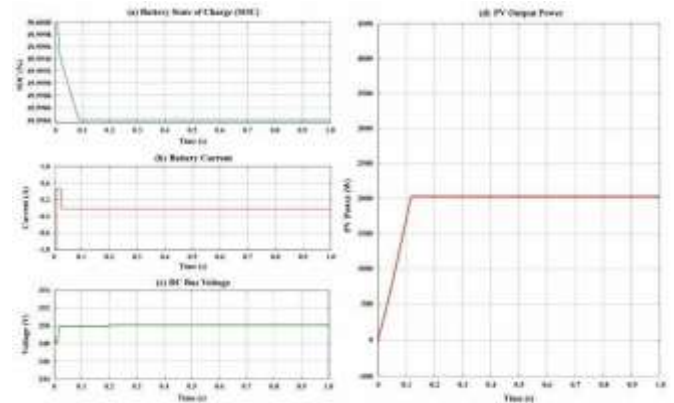


Fig4. Battery and DC Bus Performance



CONCLUSION

The hybrid solar PV–battery–grid EV charging station represents a sustainable and efficient solution for meeting the growing demand for electric vehicle charging. By integrating renewable energy from the PV array with energy storage in batteries and a grid backup, the system ensures reliable, uninterrupted power while maximizing solar energy

Charging: A
Comprehensive

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