

Review Paper Solar Electric Vehicle Charging System with Battery Optimization

Supriya S. Sidankar, Dr.Pooja Paratwar, Prof.Shivaji Bhosale

Department of Electrical Engineering,

Dattakala College of Engineering,

Savitribai Phule Pune University (SPPU) Pune, India

Email ID: supriyasidankar@gmail.com

With the rapid growth of electric vehicles (EVs) and the global emphasis on renewable energy, integrating solar photovoltaic (PV) systems into EV charging infrastructure has emerged as a sustainable solution to reduce dependency on the conventional power grid. However, challenges such as fluctuating solar irradiance, temperature variations, and inefficient battery management often limit system performance. This project presents the design and simulation of a Solar Electric Vehicle Charging System with Battery Optimisation using MATLAB/Simulink. The proposed system employs a Kalman Filter-based Maximum Power Point Tracking (MPPT) algorithm to ensure accurate and stable solar power extraction under dynamic environmental conditions. In addition, a Deep Learning-based Battery Charging Controller is developed to optimize the charging process by dynamically adjusting charging parameters according to the battery's state of charge (SoC), temperature, and health. The hybrid combination of model-based optimization and data-driven intelligent control enhances energy efficiency, minimizes temperature rise, and prolongs battery life. Simulation results demonstrate faster MPPT convergence, improved power utilization, and stable system operation under varying solar and load conditions. This study contributes to the advancement of smart, renewable-powered EV charging systems by integrating adaptive control and artificial intelligence techniques for next-generation sustainable mobility.

Keywords: Solar PV system, Electric vehicle charging, Kalman filter, MPPT, Deep learning, Battery optimization, MATLAB/Simulink.

I. INTRODUCTION

With the increasing demand for sustainable transportation and the global shift toward renewable energy, electric vehicles (EVs) have emerged as a promising alternative to conventional fossil fuel-based vehicles. However, most EVs today are charged using grid power, which often depends on non-renewable energy sources. This dependence not only increases electricity costs but also contributes indirectly to greenhouse gas emissions. To address these challenges, the integration of solar photovoltaic (PV) systems with EV charging stations offers a cleaner, decentralized, and eco-friendly solution. A solar-powered EV charging system harnesses sunlight to generate electricity, which is then used to charge the EV battery. However, variations in solar irradiance and temperature affect the efficiency of power conversion and battery charging performance. Therefore, intelligent control mechanisms are required to ensure maximum power extraction and optimal battery utilization.

Traditional grid-connected EV chargers place a significant burden on existing power infrastructure. As the adoption of EVs increases, so does the demand for charging facilities, leading to concerns about power stability and peak load management. Moreover, inefficient charging practices can degrade battery performance and shorten its lifespan. Conventional Maximum Power Point Tracking (MPPT) techniques such as Perturb and Observe (P&O) and Incremental Conductance (INC) algorithms often struggle to maintain accuracy under rapidly changing weather conditions. Likewise, the Constant Current-Constant Voltage (CC-CV) battery charging method fails to adapt to dynamic battery states such as State of Charge (SoC) and temperature. This motivates the development of an intelligent solar charging architecture that combines adaptive estimation techniques and machine learning-based battery management to enhance overall system performance and reliability.

II. LITERATURE SURVEY

Research on solar-integrated EV charging and intelligent battery management has accelerated in recent years due to rapid EV adoption and advances in power electronics and machine learning. The literature spans (a) maximum power point tracking (MPPT) for PV systems, (b) battery modelling and charging strategies including data-driven methods, and (c) system-level studies on solar-powered EV charging stations and their grid interactions. This chapter reviews representative and recent works in these areas and identifies gaps addressed by the present study.

MPPT techniques for photovoltaic systems

Traditional MPPT methods such as Perturb & Observe (P&O) and Incremental Conductance (INC) remain widely used for their simplicity, but many comparative studies report trade-offs: P&O is simple and fast but can oscillate at the MPP and mis-track under rapidly changing irradiance, while INC is more accurate but computationally heavier. Hybrid and intelligent methods (neural networks, fuzzy logic, MPC hybrids) have been proposed to improve tracking speed and robustness. A comprehensive comparative study summarizes these trade-offs and shows hybrid/data-driven MPPTs often outperform classical methods under non-ideal conditions.

Kalman filter and observer-based MPPT approaches

Observer and estimator-based MPPTs (including Kalman filter enhancements) aim to reduce measurement noise sensitivity and improve MPP estimation during transient irradiance changes. Several experimental and simulation studies demonstrate that combining Kalman filtering with MPPT (and sometimes with neural networks) improves convergence speed and reduces oscillations compared with standalone P&O/INC—particularly in noisy or rapidly varying environments. These works motivate the use of state-estimation techniques to provide a stable MPP reference for the DC–DC converter duty control.

Battery charging strategies and machine learning

Classical battery charging (CC–CV, pulse charging) is reliable but cannot adapt proactively to SoC, SoH (state of health), temperature, or aging dynamics. Recent literature has therefore explored machine learning and deep learning approaches for tasks such as SoC/SoH estimation, thermal prediction, and adaptive charging control. Deep neural networks and data-driven estimators have shown strong performance for SoC estimation and for learning optimal or near-optimal charging profiles that balance charge time, efficiency, and thermal constraints. Works in 2023–2024 report promising results for deep learning in SoC estimation and for RL/deep-RL in optimizing charging schedules under grid and PV availability constraints.

Solar EV charging systems — system studies and integrations

System-level studies and experimental prototypes of solar-powered EV charging stations illustrate practical benefits and challenges: sizing PV arrays vs. battery capacity, handling partial shading, managing intermittency, and coordinating PV, storage, and grid interactions. Recent review and simulation studies (2019–2024) analyze stand-alone and grid-tied solar EV chargers and emphasize that optimal performance requires co-design of MPPT, converter control, and battery management—rather than treating these components independently. These surveys and experimental reports support integrated solutions combining advanced MPPT and adaptive charging strategies for improved energy utilization and battery life.

Gaps identified in recent literature

From the surveyed literature the following gaps are apparent:

1. **Integrated frameworks:** Many works focus on either MPPT improvement or battery charging control in isolation. Few studies present a unified MATLAB/Simulink framework combining estimator-enhanced MPPT (e.g., Kalman filter) with a deep learning-based charging controller for EV batteries.
2. **Realistic battery-aware MPPT:** MPPT research often assumes a load that can accept whatever PV power is available; practical EV charging requires the MPPT controller to coordinate with battery constraints (SoC, temperature, SoH) to avoid thermal stress or reduced lifetime.
3. **Data-driven charging under PV intermittency:** While deep learning/RL approaches for charging and scheduling exist, there is limited work showing a deep-learning charging controller trained and evaluated within a PV+MPPT simulation loop that explicitly accounts for transient irradiance and estimator noise.
4. **Robustness to measurement noise and partial shading:** Advanced MPPT methods (observer/Kalman, NN hybrids) reduce noise sensitivity, but more comparative experimental validation under realistic partial shading and temperature profiles is still needed.

III. PROPOSED SYSTEM

The proposed project aims to design and simulate an intelligent solar-powered electric vehicle (EV) charging system that maximizes solar energy utilization and enhances battery performance through intelligent control techniques. The system integrates two major control components:

1. Kalman Filter–based Maximum Power Point Tracking (MPPT) for efficient solar power harvesting.
2. Deep Learning–based Battery Optimization Controller for adaptive, safe, and efficient battery charging.

This hybrid approach combines model-based estimation and data-driven learning to improve system reliability, energy conversion efficiency, and battery life under varying solar and load conditions. The entire framework is developed and tested in MATLAB/Simulink.

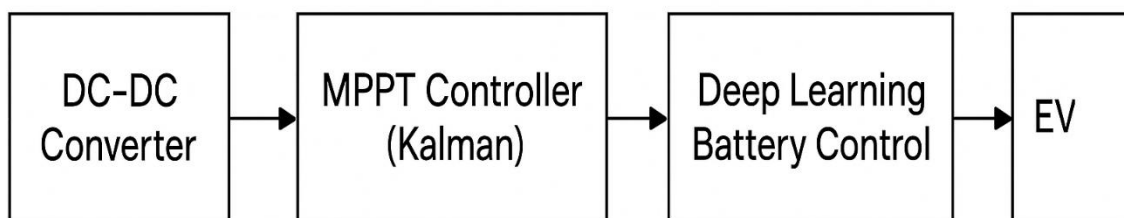


Fig.1. Proposed System

The proposed solar EV charging system consists of the following major components:

1. **Solar PV Array:**
 Converts sunlight into DC electrical energy. The PV module output varies with solar irradiance and temperature. A single-diode PV model is implemented in Simulink for accurate performance representation.
2. **DC–DC Converter (Boost Converter):**
 Steps up the PV voltage to the required level for battery charging and serves as the interface between the PV array and the battery. Its duty cycle is controlled by the MPPT algorithm.
3. **MPPT Controller (Kalman Filter–Based):**
 Utilizes a Kalman Filter to estimate the true Maximum Power Point (MPP) by filtering out measurement noise and predicting state variations under dynamic environmental conditions. It dynamically adjusts the converter duty cycle to ensure operation near the optimal power point.
4. **Battery Energy Storage Unit (EV Battery Model):**
 Represents the electric vehicle’s battery pack. The model includes SoC estimation, internal resistance, and temperature effects. The charging process is controlled by the intelligent deep learning controller.
5. **Deep Learning–Based Battery Controller:**
 A data-driven algorithm trained on simulated battery data that adapts the charging current and voltage according to SoC, SoH, and temperature. It minimizes thermal stress and extends battery life by optimizing the charge rate.
6. **MATLAB/Simulink Environment:**
 Provides a simulation platform to integrate and evaluate system performance under varying solar irradiance, temperature, and battery conditions.

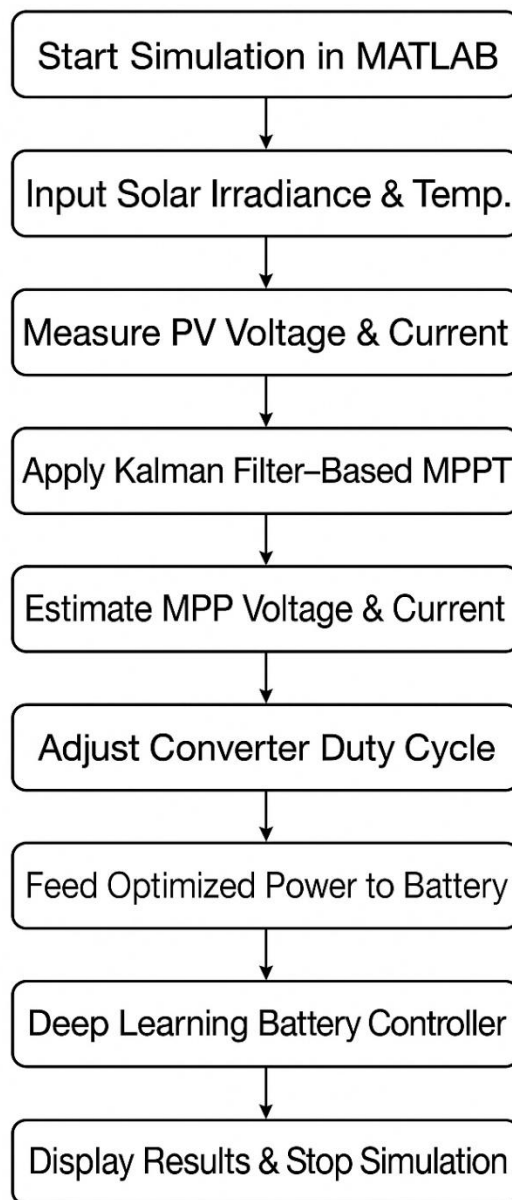


Fig.1. Flow Chart

IV. CONCLUSION

The proposed Solar Electric Vehicle Charging System with Battery Optimisation successfully integrates renewable energy utilization with intelligent control mechanisms to address the limitations of conventional EV charging methods. Through the use of Kalman Filter-based Maximum Power Point Tracking (MPPT) and Deep Learning-based Battery Charging Control, the system demonstrates significant improvements in energy extraction, stability, and charging efficiency.

Simulation results in MATLAB/Simulink confirm that:

The Kalman Filter-based MPPT achieves faster and more accurate convergence to the maximum power point under dynamic irradiance and temperature variations compared to traditional P&O and Incremental Conductance (INC) methods.

The Deep Learning Controller efficiently manages the battery charging process by adjusting voltage and current in real time based on State of Charge (SoC) and temperature, resulting in reduced energy losses and extended battery lifespan. The hybrid control framework ensures seamless coordination between solar energy harvesting and intelligent energy storage management. Overall, the system enhances solar energy utilization, battery health, and operational efficiency while supporting clean, sustainable, and

intelligent electric mobility solutions. The study validates the feasibility of combining model-based and data-driven control techniques for future EV charging infrastructures.

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