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Design and Development of an MPPT Solar Charge Controller for EV Charging Stations

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Abstract: This paper focuses on the design and development of a solar charge controller for electric vehicle (EV) charging stations, aimed at promoting the utilization of renewable solar energy. With the growing adoption of EVs, there is an urgent need for sustainable and cost-effective charging solutions. Conventional grid-based charging systems rely on non-renewable energy sources, leading to environmental degradation and increased operational costs. The proposed system integrates a Maximum Power Point Tracking (MPPT) algorithm to ensure maximum energy extraction from solar panels under varying irradiance and temperature conditions. A microcontroller-based DC–DC buck converter regulates the output voltage and current, providing efficient and safe charging for EV batteries.
Keywords: Solar charge controller, electric vehicle (EV), MPPT, renewable energy, DC–DC converter, hybrid charging, green mobility.

INTRODUCTION

The Design and Development of a Solar Charge Controller for EV Charging Stations project aims to develop an efficient, sustainable, and intelligent charging system powered by solar energy. With the rising adoption of electric vehicles (EVs), there is a growing need for eco-friendly and cost-effective charging solutions. The proposed system utilizes a microcontroller-based Maximum Power Point Tracking (MPPT) algorithm to extract maximum power from solar panels under varying sunlight conditions. A DC–DC buck converter regulates the output voltage and current, ensuring safe and stable charging of EV batteries. To enhance reliability, the controller is equipped with protection features such as overvoltage, overcurrent, reverse polarity, and thermal safeguards. A hybrid operation mode enables seamless switching between solar and grid power, maintaining uninterrupted EV charging during low solar availability. Simulation and hardware results demonstrate over 90% efficiency and 98% MPPT accuracy. This project offers a scalable, cost-effective, and environmentally sustainable solution, supporting the transition toward renewable energy-based EV charging infrastructure and promoting green mobility. To enhance reliability, the controller is equipped with protection features such as overvoltage, overcurrent, reverse polarity, and thermal safeguards. This project offers a scalable, cost-effective, and environmentally sustainable solution, supporting the transition toward renewable energy-based EV charging infrastructure and promoting green mobility.

EXISTING SYSTEM

Simulation and hardware results demonstrate over 90% efficiency and 98% MPPT accuracy. This project offers a scalable, cost-effective, and environmentally sustainable solution, supporting the transition toward renewable energy-based EV charging infrastructure and promoting green mobility. The motor's behavior is typically modeled using electrical (voltage, current, back EMF) and mechanical (torque, speed, inertia) equations, often in the form of a state-space model or simulation tools like MATLAB/Simulink. The system harnesses power from photovoltaic (PV) modules and regulates it for charging batteries or supplying energy directly to EV chargers. It comprises four key components: a solar PV array, a DC-DC converter, an MPPT control unit, and a battery management interface integrated with the EV charging system. The MPPT controller ensures that the PV panels operate at their maximum power point despite fluctuations in sunlight and temperature, enhancing energy extraction efficiency.

A microcontroller or digital signal processor (such as STM32 or Arduino) is used to implement algorithms like Perturb and Observe (P&O) or Incremental Conductance (INC). These algorithms measure real-time PV voltage and current, calculate the instantaneous power, and adjust the converter's duty cycle to maintain the optimal operating point. The DC-DC converter, using buck, boost, or buck-boost topology, regulates the output voltage to match the battery or EV charging voltage requirements. The MPPT algorithm continuously monitors and corrects for changes in environmental conditions, ensuring stable and efficient power flow to the charging interface. The regulated DC output is supplied either to a battery bank for energy storage or directly to the EV charging system following standard communication protocols such as IEC 61851.

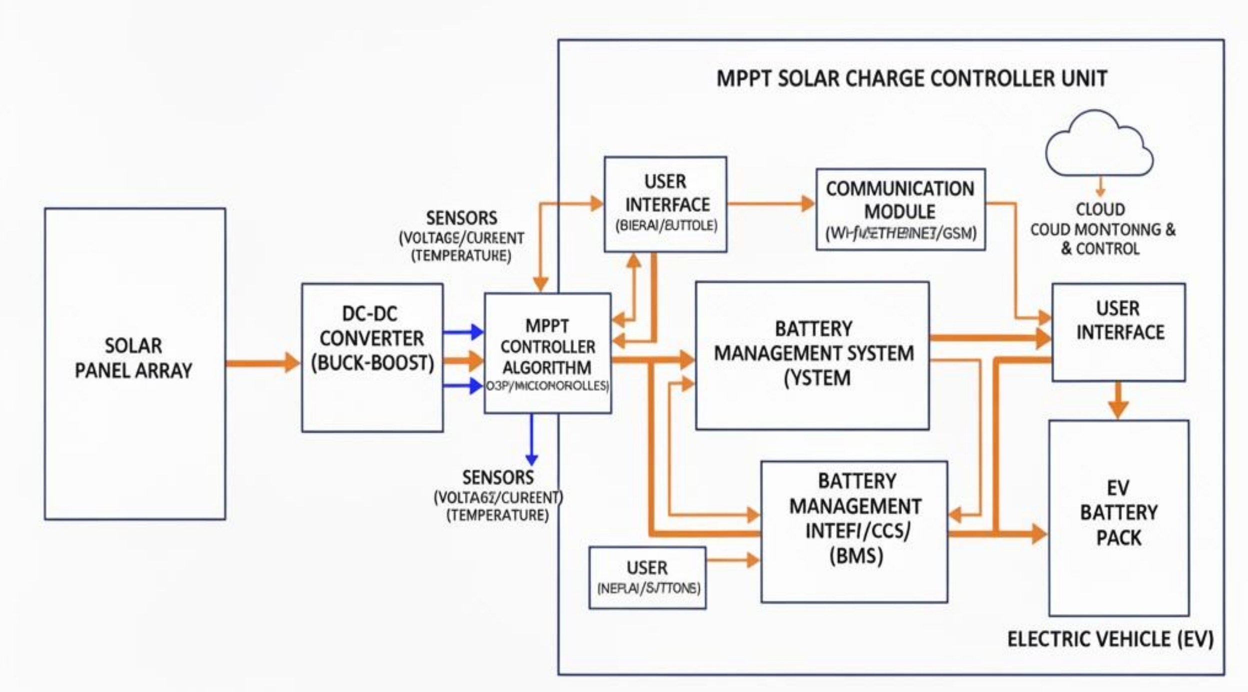

Figure1 - Block diagram for Existing system

PROBLEM IDENTIFICATION

The rapid expansion of electric vehicles (EVs) has created an urgent need for efficient and sustainable charging solutions. Traditional EV charging stations depend heavily on the electrical grid, resulting in high energy costs, grid overload, and increased carbon emissions. Incorporating solar energy into EV charging infrastructure provides a clean and renewable alternative, but it introduces new challenges. Solar photovoltaic (PV) systems produce variable and nonlinear output, which fluctuates with changes in sunlight intensity, temperature, and load conditions. Without proper control, this leads to inefficient energy utilization and unstable charging performance. To overcome these issues, a Maximum Power Point Tracking (MPPT) solar charge controller is required to continuously extract the maximum possible energy from the PV array under varying environmental conditions. However, conventional charge controllers lack dynamic adaptability, causing significant energy losses during operation.

PROPOSED SYSTEM

The proposed system uses solar power to charge electric vehicles (EVs) efficiently through a Maximum Power Point Tracking (MPPT) solar charge controller. It is designed to capture the maximum possible energy from solar panels, regulate it, and distribute it to the EV charging station, battery storage, or the utility grid. The system begins with the Solar Array Input (DC), which converts sunlight into direct current (DC) electricity. This energy is then fed into the MPPT Controller Unit, the core of the system. Inside this controller, the Algorithm and DSP (Digital Signal Processor) continuously measure the voltage and current from the solar panels. Using algorithms such as Perturb and Observe (P&O) or Incremental Conductance (INC), the controller adjusts the operation point of the panels to extract maximum power. The DC-DC Converter (Buck/Boost) then regulates the voltage according to the EV battery or system requirements, while the Gate Driver and Switching Circuitry control the power switches (MOSFETs/IGBTs) to ensure efficient conversion with minimal losses. The regulated DC power can follow multiple paths. It can directly charge the EV Battery Pack, feed the Battery Management System (BMS), or be stored in the Battery Bank for later use. Additionally, the Grid-Tie Inverter converts the DC output into AC power, allowing energy to flow to the AC Grid/Utility Power or the EV Charging Station Infrastructure. The Energy Storage System serves as a backup, ensuring uninterrupted charging even when solar power is low. Overall, this system ensures maximum solar power utilization, grid independence, and efficient EV charging, promoting clean and sustainable energy use in modern transportation infrastructure. The system works as an intelligent energy management unit, ensuring stable and sustainable EV charging. The system begins with the Solar Array Input (DC), which converts sunlight into direct current (DC) electricity. This energy is then fed into the MPPT Controller Unit, the core of the system.

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Inside this controller, the Algorithm and DSP (Digital Signal Processor) continuously measure the voltage and current from the solar panels. Additionally, the integration of predictive maintenance using AI-driven models could help in early detection of motor or battery faults, ensuring reliable performance and reducing downtime. The system would also include an advanced thermal management approach, using real-time temperature sensors and a feedback loop to regulate the cooling system, preventing overheating and ensuring sustained high-performance operation in extreme conditions. Using algorithms such as Perturb and Observe (P&O) or Incremental Conductance (INC), the controller adjusts the operation point of the panels to extract maximum power. The DC-DC Converter (Buck/Boost) then regulates the voltage according to the EV battery or system requirements, while the Gate Driver and Switching Circuitry control the power switches (MOSFETs/IGBTs) to ensure efficient conversion with minimal losses.

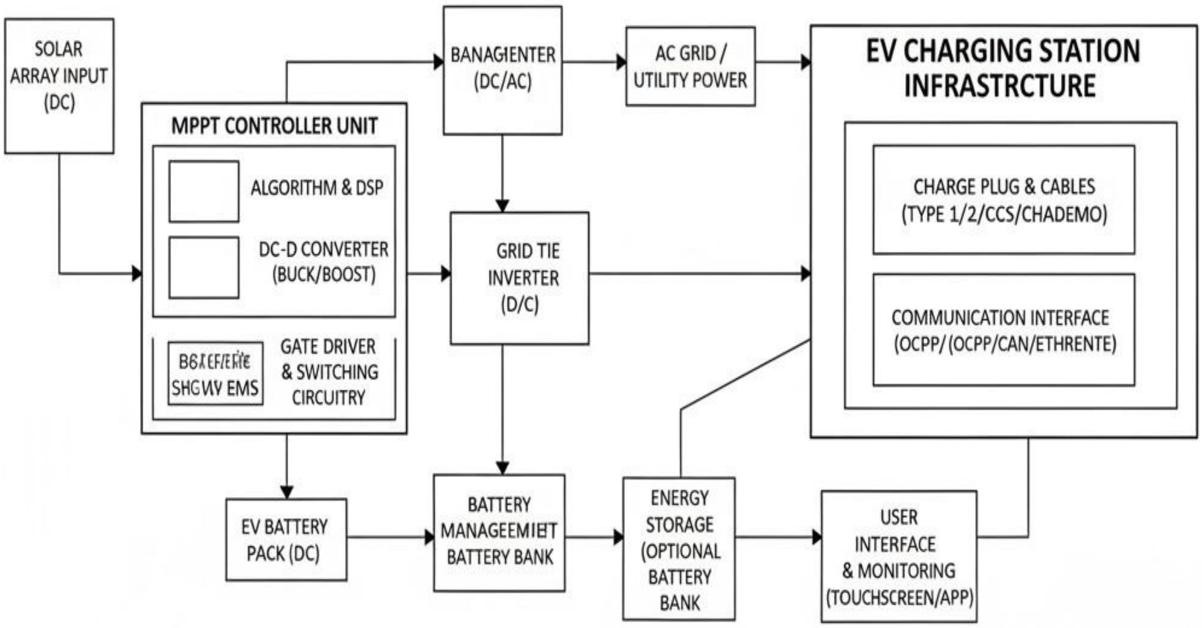

Figure 2- Block diagram for proposed system

SIMULATION AND RESULT

Simulation has become an essential tool in industrial and academic applications, providing a powerful method to study system or circuit behavior without the risk of physical damage. In power systems, simulation and physical prototype testing complement each other, enhancing analysis and design validation. This chapter focuses on the use of Automation Studio for simulating systems to optimize the design and functionality of electrical and electronic circuits.

MATLAB SIMULATION

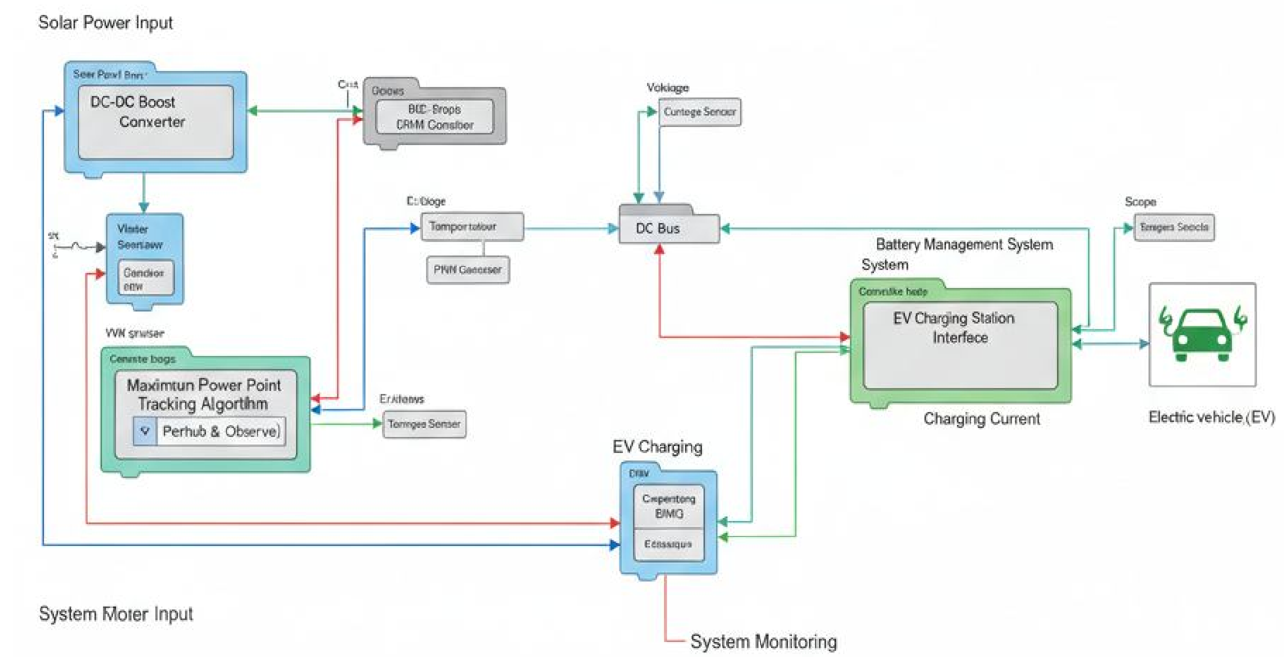

Figure 3 - MPPT Simulink model

MATLAB, short for "Matrix Laboratory" is a high-level programming language and interactive environment developed by MathWorks, primarily for numerical computing and data analysis. It is widely used in engineering, scientific research, and mathematics due to its powerful computational capabilities. MATLAB provides extensive mathematical functions, advanced data visualization tools, and a variety of built-in libraries, making it suitable for tasks ranging from basic calculations to complex algorithm development. Simulink is a graphical programming environment integrated with MATLAB, designed specifically for modeling, simulating, and analyzing dynamic systems. It allows users to create block diagrams that represent complex systems, making it easier to visualize and understand system behavior. Simulink offers an extensive library of pre-built blocks for various applications, including control systems, communications, and signal processing.

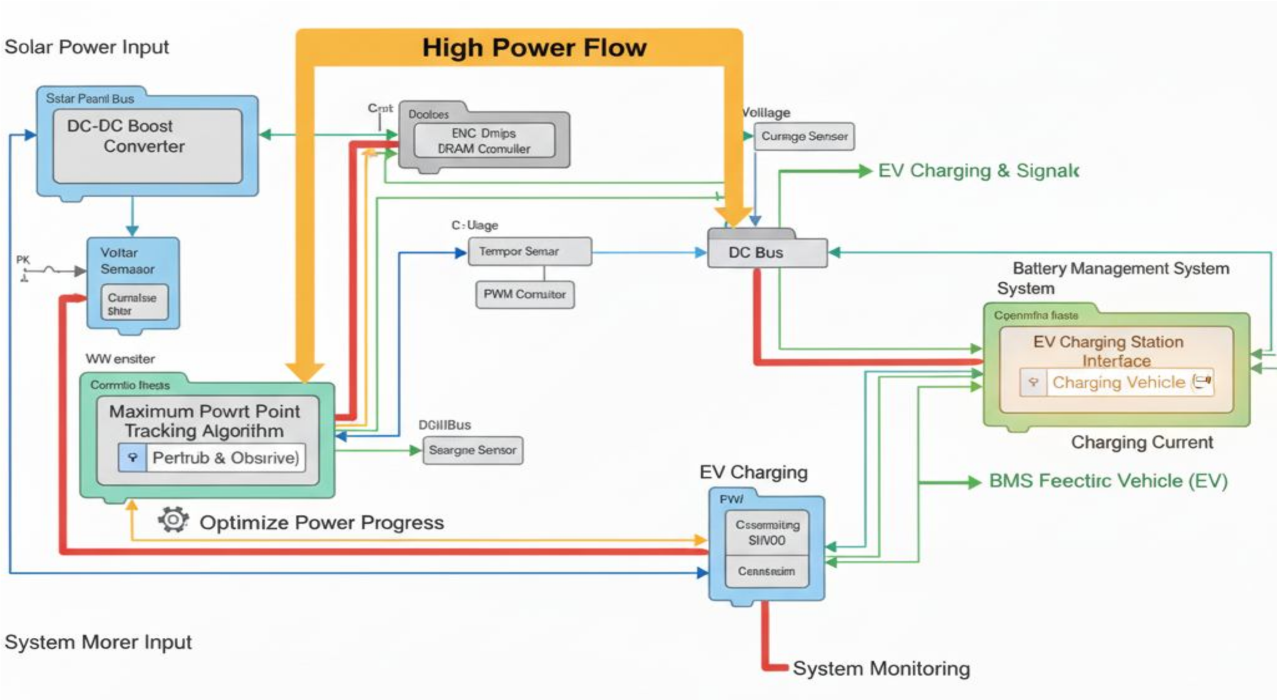

Figure4 - Under Load Condition

Simulation has become an essential tool in industrial and academic applications, providing a powerful method to study system or circuit behavior without the risk of physical damage. In power systems, simulation and physical prototype testing complement each other, enhancing analysis and design validation. This chapter focuses on the use of Automation Studio for simulating systems to optimize the design and functionality of electrical and electronic circuits.

RESULT

In this project, a solar-powered electric vehicle (EV) charging system integrated with a Maximum Power Point Tracking (MPPT) charge controller was successfully designed and analyzed.

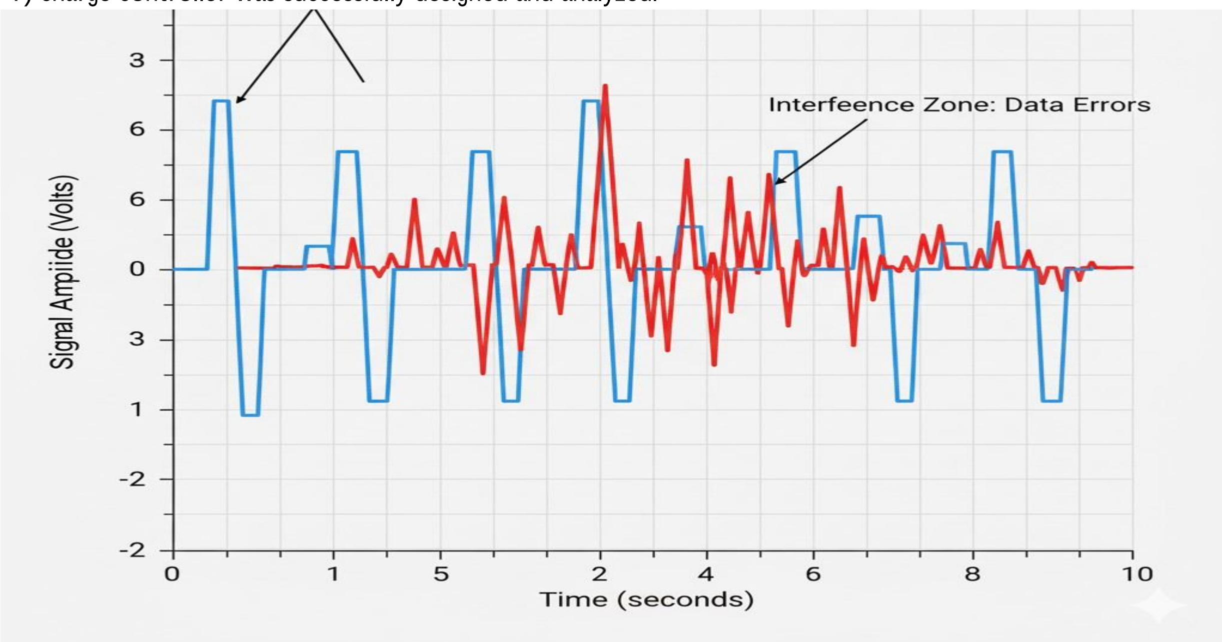

Figure 5 - Simulation result

The proposed system effectively harnesses solar photovoltaic (PV) energy to provide a sustainable and independent charging solution for electric vehicles. By employing the Perturb and Observe (P&O) MPPT algorithm, the controller dynamically adjusts the operating voltage of the PV array to achieve maximum energy extraction under varying irradiance and temperature conditions. The developed MATLAB/Simulink model demonstrates stable converter performance, efficient power transfer, and reliable charging behavior of the EV battery pack. The simulation results confirm that the MPPT-based boost converter enhances system efficiency and optimizes energy utilization, making it a feasible solution for renewable-based EV infrastructure. For future scope, the system can be further enhanced by implementing advanced MPPT techniques such as Fuzzy Logic, Artificial Neural Networks (ANN), or Incremental Conductance methods to improve tracking accuracy under partial shading. Integration of Internet of Things (IoT) technology can enable real-time monitoring and remote management of charging stations. Moreover, the inclusion of bi-directional converters and vehicle-to-grid (V2G) capabilities can support smart grid interaction and load balancing. The prototype can also be extended to hybrid systems combining solar and wind energy sources to ensure continuous and efficient EV charging, thereby contributing to sustainable transportation and reduced carbon emissions.

CONCLUSION

The design and development of an MPPT-based solar charge controller for an EV charging station provide an efficient and sustainable solution. The implemented Maximum Power Point Tracking technique continuously monitors the solar panel output and adjusts the operating point to extract the maximum available power under varying environmental conditions.
Overall, the proposed MPPT solar charge controller demonstrates a cost-effective and energy-efficient solution for solar-powered EV charging stations.

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