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MPPT Solar Controller: A Theoretical Design and Prototype Development

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Abstract: *This paper discusses the theoretical design and ongoing prototype development of a Maximum Power Point Tracking (MPPT) solar controller system aimed at efficient energy harvesting and smart load management. The system is designed to optimize energy extraction from a solar panel using MPPT algorithms, with smart load management for real-time power distribution. The controller incorporates cloud-based monitoring, AI optimization, and a user-friendly interface. The system is expected to deliver robust, efficient, and safe operation under varying environmental conditions*

Keywords: MPPT, solar energy, load management, AI optimization, cloud monitoring, prototype development

I. INTRODUCTION

The increasing demand for renewable energy solutions has led to the development of more efficient solar energy systems. However, the efficiency of solar panels depends on their ability to operate at the maximum power point (MPP), which fluctuates based on environmental conditions. To address this, Maximum Power Point Tracking (MPPT) technology is employed to ensure maximum energy extraction from the solar panels.

This paper presents the theoretical design and prototype development of an MPPT-based solar controller system. The system is designed to optimize power extraction from an 18V solar panel, deliver a stable 12V, 5A output, and manage connected loads intelligently. Additionally, the system integrates cloud-based remote control, AI-based performance optimization, and a user-friendly interface for real-time system management.

II. LITERATURE SURVEY

Atri et al. (2021) explored the design and implementation of MPPT algorithms in solar charge controllers. Their findings showed significant improvement in energy extraction compared to conventional methods, especially when using algorithms like Perturb and Observe (P&O) and Incremental Conductance.

Acharya and Aithal (2020) presented a comparative study between MPPT and PWM-based solar charge controllers. Their work highlighted the superiority of MPPT controllers in optimizing solar energy conversion efficiency, particularly in variable weather conditions.

Uprety and Lee (2021) focused on the development of a low-power photovoltaic energy harvester with an irradiance-aware, auto-configurable MPPT system. Their design optimized performance even under fluctuating irradiance, demonstrating the versatility of adaptive MPPT algorithms in real-world solar harvesting applications.

Patel and Doshi (2019) introduced a robust MPPT controller design for grid-independent solar energy systems. Their research emphasized the importance of efficient load management and smart distribution systems in maximizing the energy utility of the solar panels.

These studies collectively underscore the importance of MPPT technology in modern solar controllers, demonstrating its capacity to enhance energy efficiency, adapt to environmental variability, and improve load management.

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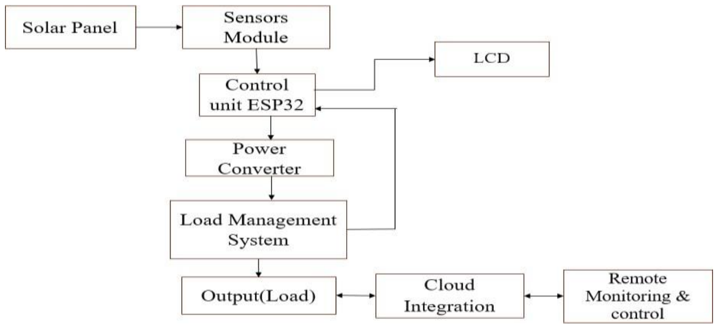
III. SYSTEM DESIGN



The block diagram of the MPPT solar controller presents a clear depiction of how the components interact within the system. Here's an overview of the key elements:

[1]. Solar Panel: The solar panel generates electricity from sunlight. It is rated at 18V and 75W, supplying the system with variable output power depending on the sunlight intensity.

[2]. MPPT Control Unit (ESP32): The ESP32 microcontroller serves as the system's brain, running the MPPT algorithm. It adjusts the power point of the solar panel to ensure maximum energy extraction. The microcontroller also supports cloud integration for real-time monitoring and control.

[3]. Buck Converter: The buck converter steps down the 18V from the solar panel to a stable 12V, which is used to charge the battery and power the loads. It is a critical component in maintaining efficient voltage regulation.

[4]. Sensors Module: Voltage and current sensors continuously monitor the panel's performance. These sensors feed data to the MPPT unit to optimize the system's power output.

[5]. Load Management System: This system manages the distribution of power to various connected loads and the battery. It ensures that the energy is used efficiently, prioritizing critical loads when necessary.

[6]. Battery: The 12V, 100Ah battery stores excess energy generated by the solar panel. This stored energy is used when sunlight is insufficient to power the loads directly.

[7]. LCD Display: A 16x2 or 20x4 LCD provides real-time feedback on the system's status, including current, voltage, power, and battery health.

IV. EXPECTED OUTCOME

[1]. Efficient Energy Harvesting: MPPT algorithms ensure that the solar panel operates at its maximum efficiency, maximizing energy harvested even under varying irradiance conditions.

[2]. Smart Load Management: The system dynamically distributes power to connected loads and the battery based on real-time demand, improving overall energy efficiency and usage.

[3]. Remote Control and Monitoring: Cloud-based monitoring allows users to remotely track and adjust the system's performance through a web-based or mobile interface, ensuring optimal operation even from a distance.

[4]. AI-Based Optimization: The system leverages AI to predict energy usage patterns and optimize the operating parameters of the solar controller, improving long-term efficiency and reliability.

[5]. User-Friendly Interface: The system features an intuitive LCD display for local monitoring, along with a simple web-based interface for remote control, ensuring ease of use for users with various technical backgrounds.

[6]. Safety and Reliability: Built-in safety features, including over-voltage and over-current protection, ensure the system operates reliably under different environmental conditions.

V. CONCLUSION

The theoretical design and prototype development of the MPPT solar controller presented in this paper offer a robust solution for efficient energy harvesting, load management, and remote monitoring. The integration of MPPT algorithms, AI optimization, and cloud-based control enhances the overall system performance. Future work will focus on testing the prototype under real-world conditions and scaling the design for larger solar installations

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