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ANALYSIS OF MICROCONTROLLER-BASED MAXIMUM POWER POINT CHARGE CONTROLLER FOR PHOTOVOLTAIC SYSTEMS ON TEMPERATURE EFFECT

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Abstract

This paper presents a comprehensive analysis of a microcontroller-based Maximum Power Point (MPP) charge controller designed for photovoltaic (PV) systems. The MPP charge controller plays a crucial role in efficiently harvesting energy from solar panels by dynamically adjusting the operating point to maximize power output. The integration of a microcontroller enables intelligent control algorithms to optimize the charging process, enhancing system performance and reliability. This study investigates the design, operation, and performance evaluation of the proposed MPP charge controller through simulation and experimental validation. The results demonstrate the effectiveness and advantages of employing a microcontroller-based approach in PV systems for improved energy conversion efficiency and reliability.

Key word: Maximum Power Point Tracking (MPPT), Charge Controller, Microcontroller, Photovoltaic Systems, Energy Efficiency, Simulation, Experimental Validation.

Introduction

In recent years, the increasing adoption of renewable energy sources, particularly solar photovoltaic systems, has led to the development of efficient power conversion technologies. A key component in such systems is the charge controller, which ensures optimal power extraction from solar panels. Traditional charge controllers exhibit

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limitations in adapting to varying environmental conditions and load demands, thus compromising energy conversion efficiency. To address these challenges, microcontroller-based charge controllers have emerged as a promising solution, offering advanced control algorithms and real-time monitoring capabilities. This paper aims to analyze the design and performance of a microcontroller-based Maximum Power Point (MPP) charge controller for photovoltaic systems.

With the increasing demand for sustainable energy solutions, solar photovoltaic (PV) systems have emerged as a viable option for renewable electricity generation. However, the efficiency of PV systems heavily relies on their ability to extract the maximum available power from solar panels, especially in varying environmental conditions. Maximizing power extraction requires sophisticated control mechanisms that continuously track the Maximum Power Point (MPP) of the PV modules. Traditional charge controllers often fall short in adapting to changing irradiance levels and temperature conditions, leading to suboptimal energy conversion efficiency.

To address these challenges, microcontroller-based Maximum Power Point Tracking (MPPT) charge controllers have gained prominence due to their ability to integrate advanced control algorithms and real-time monitoring capabilities. These controllers employ microcontrollers to dynamically adjust the operating point of the PV system, ensuring optimal power extraction under varying conditions. Despite their growing adoption, there is a need for comprehensive analysis and evaluation of microcontroller-based MPPT charge controllers to assess their performance, efficiency, and reliability in real-world applications.

This study aims to fill this gap by conducting a detailed analysis of a microcontroller-based MPPT charge controller designed for PV systems. By investigating the design, operation, and performance of the proposed charge controller, this research seeks to provide valuable insights into its effectiveness in maximizing power extraction from solar panels. Through a combination of simulation studies and experimental validation, the study aims to evaluate the efficiency, response time, stability, and scalability of the microcontroller-based charge controller under various operating conditions.

The findings of this study are expected to contribute to the advancement of PV system technology by providing practical guidance for the design and implementation of efficient charge control mechanisms. Moreover, the insights gained from this analysis can inform future research and development efforts aimed at enhancing the performance and reliability of microcontroller-based MPPT charge controllers, ultimately accelerating the adoption of solar energy as a sustainable electricity generation solution.

Solar MPPT Charge Control Techniques:

Solar photovoltaic (PV) systems have been subject to extensive research in recent decades aimed at enhancing the efficiency of solar PV modules. The inherent non-linearity

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of the IV curve of solar PV modules necessitates techniques for tracking the Maximum Power Point (MPP), corresponding to the maximum voltage and current on the IV curve. Consequently, a variety of Maximum Power Point Tracking (MPPT) techniques have been developed, with Perturb & Observe (P&O) being the most commonly utilized in commercial systems due to its simplicity, cost-effectiveness, and ease of implementation [1]. However, the P&O technique has been observed to exhibit sluggish tracking of the MPP under rapidly changing irradiance conditions, often resulting in oscillations around the MPP. Addressing these shortcomings, Ali F. Murtaza et al. introduced a novel hybrid MPPT technique that combines the P&O and Fractional Open Circuit Voltage (FOCV) methods to overcome the inherent deficiencies of the P&O technique. This hybrid technique demonstrates enhanced robustness in tracking the MPP even under frequent irradiance changes and exhibits reduced oscillations around the MPP compared to P&O, as validated through simulations conducted using MATLAB/SIMULINK.

Weidong Xiao et al. introduced an analysis of the performance of photovoltaic modules under non-ideal conditions and proposed topologies to mitigate performance degradation caused by these conditions [2]. Their study revealed a significant decrease in the peak power point of a module due to even slight shading, which propagated through other non-shaded modules connected in series. Based on this finding, two parallel module connection topologies were outlined, and various dc/dc converter technologies necessary for the design were compared in terms of their dynamic models, frequency characteristics, and component costs.

Jun Pan et al. proposed a design for a PV charging system with MPPT based on the output characteristics of a PV array and battery charging characteristics [3]. Their approach employs a MPPT strategy based on the output current of a DC/DC converter, utilizing a variable step duty cycle to implement MPPT of the PV array. Furthermore, an optimal charging strategy combining MPPT charging and variable intermittent current charging was adopted for battery charging management, enhancing charging speed and state of charge while ensuring battery longevity.

In standalone DC systems, where a DC-DC converter interconnects solar PV and batteries, incorporating MPPT is crucial for maximizing solar PV utilization [4]. Sandeep Anand et al. addressed limitations in existing techniques where excess power flows into the battery during high state of charge (SOC) and partial loading conditions, potentially reducing battery life. Their proposed charge controller scheme ensures optimal utilization of solar PV and battery capacities without compromising battery life, as validated through detailed simulation and experimental studies on a laboratory prototype.

Proposing a new MPPT algorithm for photovoltaic arrays, Mohamed Azab introduced a technique that directly controls the power drawn from the PV, offering simplicity, high convergence speed, and independence from PV array characteristics [5]. The algorithm utilizes an ON/OFF power controller with hysteresis band to operate a Buck chopper,

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ensuring that the PV module operates at its maximum power computed from the MPPT algorithm. Experimental results demonstrate effective MPP tracking even under sudden changes in irradiation levels.

Siwakoti et al. [6] have introduced a novel, cost-effective, and highly accurate microcontroller-based Maximum Power Point Tracking (MPPT) system tailored for solar photovoltaic setups. This system ensures swift adaptation to rapidly changing environmental conditions. Employing Pulse Width Modulation (PWM) technique, it efficiently manages the power output of a boost DC/DC converter to maintain it at its peak value while concurrently overseeing the battery charging process. The implementation incorporates the Incremental Conductance algorithm for enhanced performance.

In a similar vein, B.R. Sanjeeva Reddy et al. [7] have proposed PWM methodologies to regulate the output power of a boost converter, optimizing it for maximum efficiency and synchronously managing battery charging. They conducted parameter extraction, model evaluations, and analysis of the boost converter using a MATLAB/Simulink model.

Yang Du et al. [8] have analyzed a battery-integrated boost converter designed for module-based series-connected photovoltaic (PV) systems. In this setup, each PV module is equipped with its own battery and DC/DC converter, facilitating MPPT and battery charging. This converter's application in module-based series-connected PV systems helps maintain string voltage and eliminates the need for an additional voltage amplification stage. They presented a thorough steady-state analysis of the converter to establish power flow equations and outlined three key advantages over conventional series-connected boost converters. Simulation and experimental results from a laboratory prototype were also provided.

Methodology:

The following method was used for evaluating the performance of an MPPT (Maximum Power Point Tracking) charge controller:

1. Design and set up an experimental testbed to evaluate the performance of MPPT charge controllers and PWM solar charge controllers under controlled conditions. The testbed should include:
   - Solar panel(s) with known specifications and characteristics.
   - Battery bank for energy storage and load simulation.
   - MPPT charge controller and PWM solar charge controller units for comparison.
2. Measure and record the following parameters for both MPPT and PWM charge controllers:
   - Solar panel voltage and current under varying irradiance levels and temperatures.
   - Charging voltage and current delivered to the battery.

Result/Analysis

Using Simulink in MATLAB, the comparison of SCC (solar charger controller) between MPPT (Maximum Power Point Tracker) and PWM (Pulse Width Modulation) produces a set of comparison graphs that include input, output, current, and voltage. From Figure 1

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to Figure 4, it can be concluded that the input current value remains stable for varying temperatures and irradiance levels, with the exception of the condition at 1000W/m² irradiance and a temperature of 35°C. Under this condition, the PWM charger controller experiences a decrease in current, as shown in Figure 4.

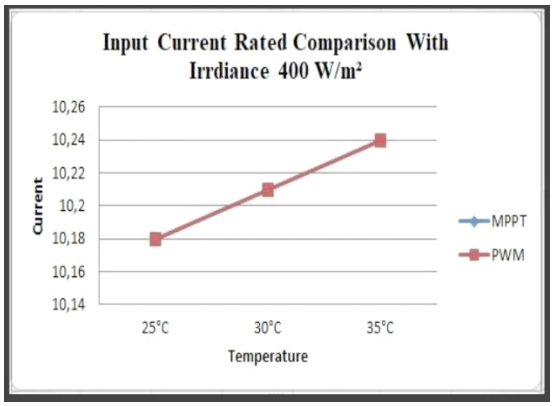

Figure 1. Graph of Input Current with an Irradiance of 400 W/m².

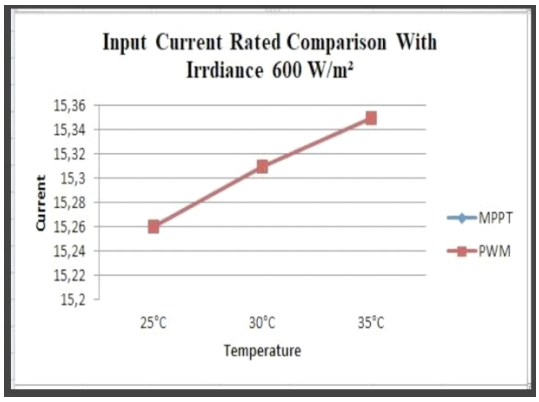

Figure 2. Graph of Input Current with an Irradiance of 600 W/m².

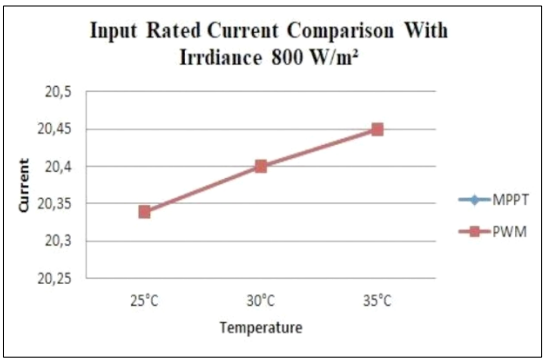

Figure 3. Graph of Input Current with Irradiance 800 W/m²

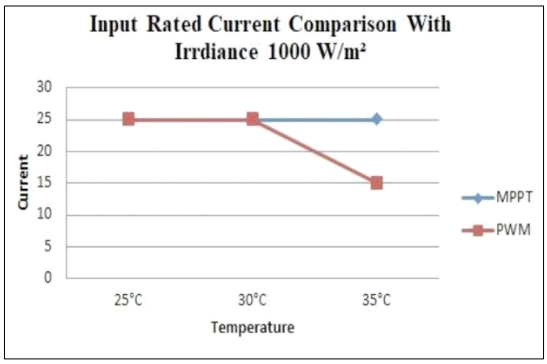

Figure 4. Graph of Input Current with Irradiance 1000 W/m².

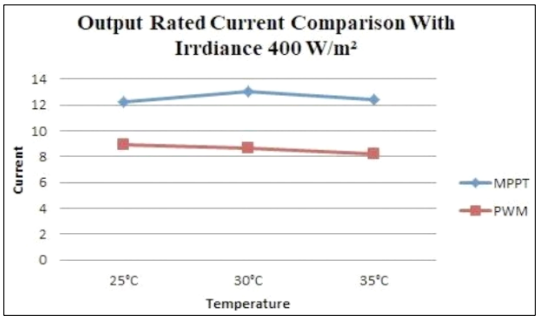

Figure 5. Graph of Comparison of Output with an of 400 W/m².

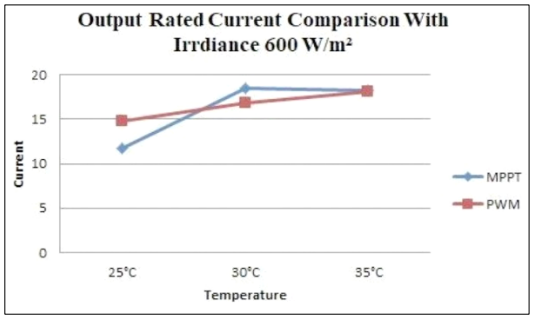

Figure 6. Graph of Comparison of Output with an Irradiance of 600 W/m².

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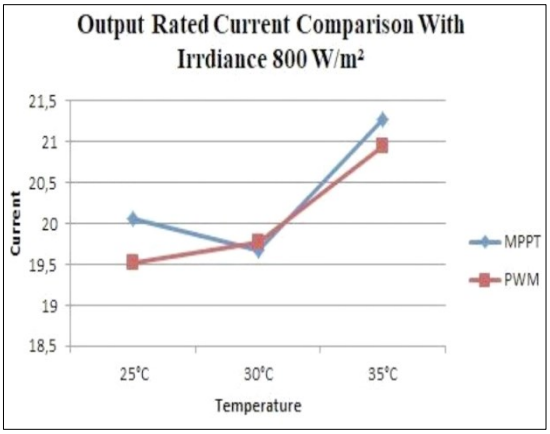

Figure 7. Comparison of Output Graph with Irradiance of 800 W/m²

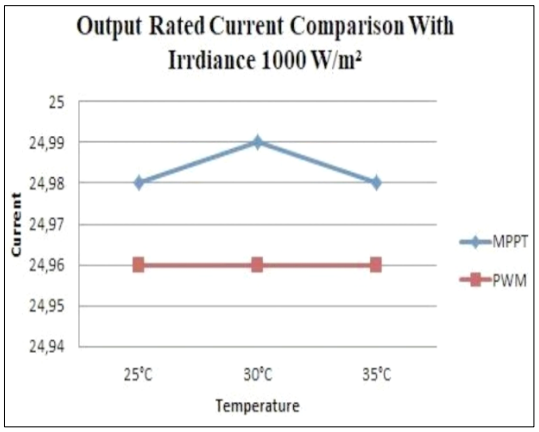

Figure 8. Graph of Comparison of Output with Irradiance of 1000 W/m².

At 800 W/m² irradiance, the current output of the MPPT controller is superior to that of the PWM controller, although it decreases when the temperature reaches 30°C, as shown in Figure 10. Figures 9 through 11 illustrate the current output from both the MPPT and PWM charger controllers. It can be concluded that, across a range of low to high temperatures, the current output from the MPPT controller is consistently better than that of the PWM controller, even though the difference is slight.

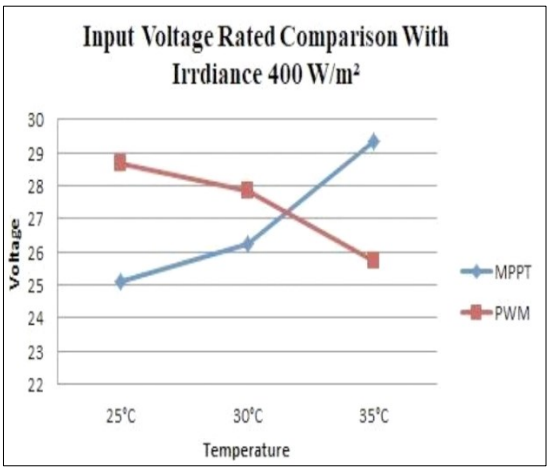

Figure 9. Graph of Input Voltage with an Irradiance of 400 W/m²

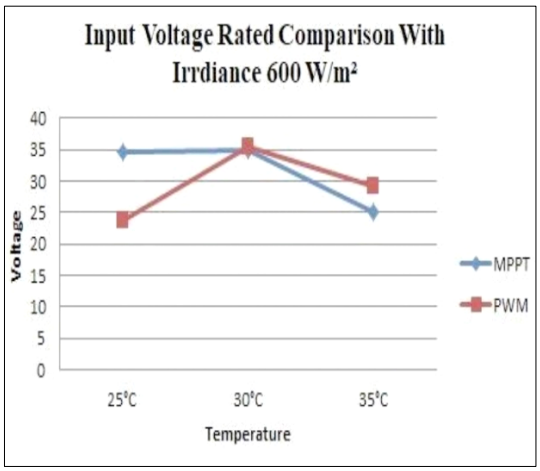

Figure 10. Graph of Input Voltage with an irradiance of 600 W/m².

In Figure 12, with an input voltage at an irradiance of 400, the PWM charger controller decreases at 350°C, while the MPPT controller increases. At this irradiance, the MPPT controller performs better at lower temperatures, whereas the PWM controller is more effective at higher temperatures.

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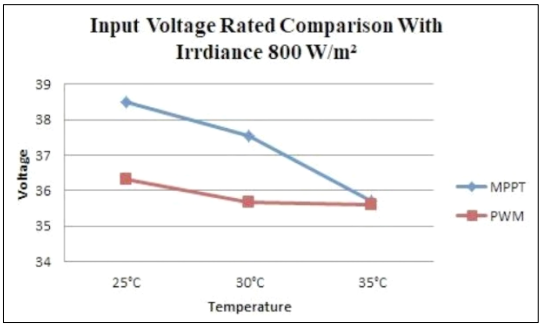

Figure 11. Graph of Input Voltage with Irradiance of 800 W/m²

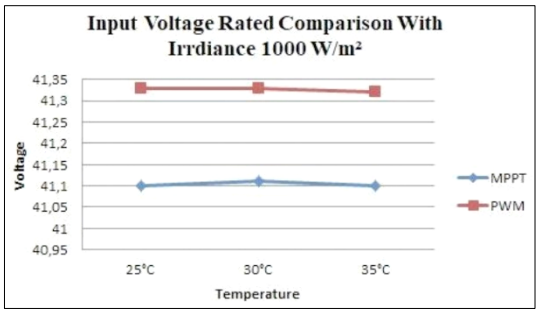

Figure 12. Graph of Input Voltage with Irradiance of 1000 W/m².

At low temperatures, the MPPT controller performs better, while at high temperatures, both controllers exhibit the same voltage value. Across the range from low to high temperatures, the PWM control outperforms the MPPT. Based on the observations from Figure 12 to Figure 15 and the discussion above, it can be concluded that although both MPPT and PWM controllers experience fluctuations in input voltage, the PWM controller is more effective than the MPPT controller at an irradiance of 1000 W/m².

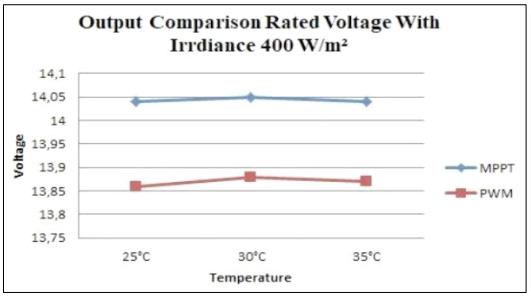

Figure 13. Graph of Output Voltage with Irradiance of 400 W/m².

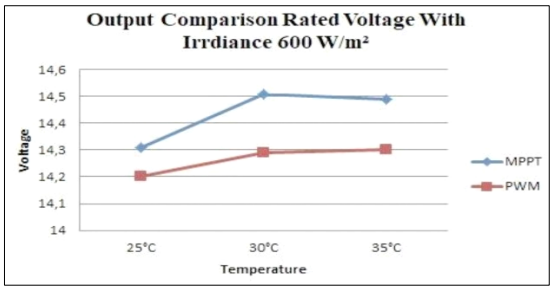

Figure 14. Graph of Output Voltage with an Irradiance of 400 W/m².

Figures 13 through 16 illustrate the output voltages for both MPPT and PWM controllers. From these figures, it can be concluded that the MPPT output voltage has increased and is superior to that of the PWM controller.

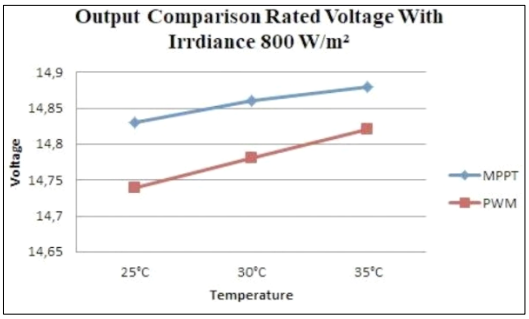

Figure 15. Graph of Output Voltage with Irradiance of 800 W/m².

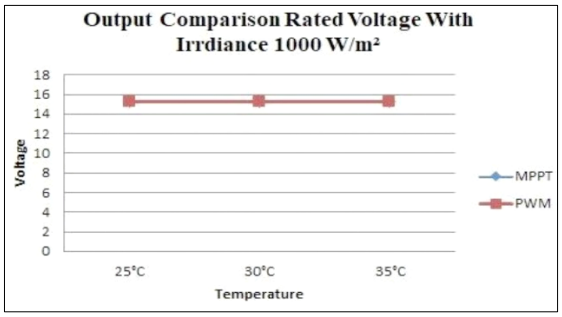

Figure 16. Graph of Output Voltage with Irradiance of 1000 W/m².

From the graph above, it can be concluded that while both the MPPT and PWM controllers experience an increase in voltage, the MPPT output voltage is superior. Despite both controllers showing stable output voltages, the MPPT charger controller generally outperforms the PWM controller, except at high irradiance levels. Additionally, Figure 9 shows that at an irradiance of 400, the PWM charger controller decreases at 350°C, while the MPPT controller increases. At this irradiance, the MPPT controller performs better at low temperatures, while the PWM controller is more effective at high temperatures.

Discussion

At an irradiance of 800 W/m², the current output of the MPPT controller is superior to that of the PWM controller, despite a decrease when the temperature reaches 30°C, as shown in Figure 9. Figures 7 through 10 indicate that, from low to high temperatures, the MPPT controller generally provides better current output than the PWM controller, although the difference is minor.

At low temperatures, the MPPT controller outperforms the PWM controller, while at high temperatures, both controllers show the same voltage value. From Figures 11 to 14, and based on the discussion above, it can be concluded that while both MPPT and PWM controllers experience fluctuations in input voltage, the PWM controller performs better at 1000 W/m² irradiance.

Figures 15 through 18 show that the output voltage of the MPPT controller has increased and is superior to that of the PWM controller. Although both controllers exhibit stable output voltages, the MPPT controller consistently performs better except at high irradiance levels, where both controllers remain stable.

In Figure 9, at an irradiance of 400 W/m², the PWM controller's voltage decreases at 350°C, while the MPPT controller's voltage increases. At this irradiance level, the MPPT controller performs better at low temperatures, whereas the PWM controller shows improved performance at high temperatures.

Conclusion:

In conclusion, the paper summarizes the key findings and contributions of the analysis. The effectiveness of the microcontroller-based charge controller in improving energy conversion efficiency and reliability in photovoltaic systems is highlighted, along with potential avenues for future research and development.

Acknowledgement

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