Comparative Analysis of Perturb & Observe and Particle Swarm Optimization Based MPPT for PV Systems Under Uniform and Partial Shading Conditions

Muddamsetty Vishnu[1] Teja, Ramireddy Yashoda[2], Ponnapureddy Deepika[3], Vanam Kavya[4]

[1234] Department of Electrical and Electronics Engineering, GPREC, Kurnool, Andhra Pradesh, India

Corresponding Author Email: vishnuteja263@gmail.com

How to Cite this Article:

Teja, M. V., Yashoda, R., Deepika, P. & Kavya, V. (2026). Comparative Analysis of Perturb & Observe and Particle Swarm Optimization Based MPPT for PV Systems Under Uniform and Partial Shading Conditions. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(04). https://doi.org/10.55041/ijcope.v2i4.688

https://doi.org/10.55041/ijcope.v2i4.688

Abstract--

In this paper, a comparative study is conducted between two MPPT methods: Perturb and Observe (P&O) and Particle Swarm Optimization (PSO) algorithms for photovoltaic (PV) solar energy harvesting. An experiment setup was established using a PIC16F72 microcontroller together with a boost converter to charge a 12V battery from a 12V, 3W PV cell. The system measures both PV cell voltage and battery voltage using resistive voltage dividers and calculates the appropriate PWM duty cycle to harvest maximum energy. In addition to the hardware implementation, MATLAB/Simulink software was used to develop PV models of 50W cells to simulate the P&O algorithm at uniform irradiance and PSO under partial shading and varying irradiance levels. Results demonstrate that although P&O performs well at uniform irradiance (~88% efficiency), it fails to track the global maximum power point (MPP) under partial shading. PSO, on the other hand, successfully determines the global MPP under partial shading conditions, achieving ~95% tracking efficiency. The study validates the feasibility of cost-effective MPPT implementation on an 8-bit microcontroller for standalone solar charger applications.

Keywords—*MPPT; Solar PV; Perturb and Observe; Particle Swarm Optimization; Partial Shading; Boost Converter; PIC Microcontroller; PWM*

I. INTRODUCTION

The use of renewable energy sources like solar photovoltaic (PV) has become one of the major solutions for meeting increasing energy demands while protecting the environment. The power-voltage (P-V) characteristic of solar panels is nonlinear, with an operating point that corresponds to maximum power delivery, called the Maximum Power Point (MPP). This MPP varies depending on irradiance and temperature changes, requiring tracking algorithms known as MPPT controllers.

Classical MPPT algorithms such as Perturb and Observe (P&O) and Incremental Conductance (INC) operate adequately under constant irradiance. However, when partial shading occurs due to cloud cover, nearby buildings, or trees, multiple local peaks appear on the P-V curve, making global peak tracking impossible and causing power losses of 20–70% [1], [2].

Meta-heuristic algorithms such as Particle Swarm Optimization (PSO) have shown superior performance under partial shading, as they search globally and escape local minima [3], [4]. In this paper, a hardware design of an MPPT solar charger using the PIC16F72 microcontroller is presented along with MATLAB/Simulink simulations comparing P&O and PSO under uniform and partial shading conditions.

The hardware design employs a 12V, 3W monocrystalline solar panel, boost converter circuit, voltage sensing circuitry, and PIC16F72 controller with a P&O MPPT algorithm. Simulations further investigate a 50W solar panel model under standard test conditions and various partial shading scenarios.

II. SYSTEM ARCHITECTURE AND HARDWARE DESIGN

A. System Block Diagram

The hardware model consists of five main modules: (1) solar panel input module, (2) voltage sensors for PV and battery voltages, (3) PIC16F72 microcontroller as the MPPT controller, (4) boost converter power module, and (5) 12V 1Ah lead-acid battery with LCD display.

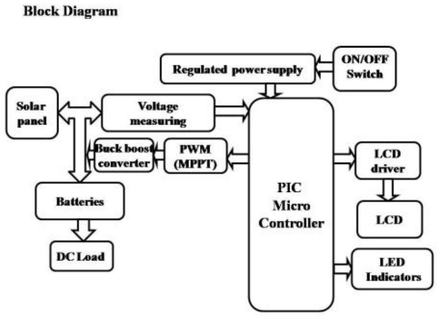

Fig. 1: Block diagram of the PIC16F72-based solar MPPT system

B. Solar Panel

A 12V/3W monocrystalline solar panel serves as the energy source. At Standard Test Conditions (STC: 1000 W/m² irradiance, 25°C cell temperature), the panel delivers 12.4V open-circuit voltage and 250 mA short-circuit current. Output voltage varies significantly with irradiance—from approximately 5V under overcast conditions to over 17V under bright sunlight—necessitating an MPPT system.

C. Voltage Sensing Circuit

Two resistive voltage dividers using 10 kΩ and 1 kΩ resistors measure the solar panel and battery terminal voltages. The divider ratio reduces the maximum voltage (18V) to approximately 1.6V, within the PIC16F72 ADC input range (0–5V). The sensing equation is:

$$V\_ADC = V\_in \times [R2/(R1 + R2)] = V\_in \times [1k/(10k + 1k)] \approx 0.0909 \times V\_in$$

Sensor 1 monitors the solar panel terminal voltage; Sensor 2 measures the battery terminal voltage.

D. PIC16F72 Microcontroller

An 8-bit PIC16F72 microcontroller (Microchip Technology) serves as the main processing unit, operating at 20 MHz using an external crystal oscillator. Key peripherals include: (i) two 10-bit ADC channels (RA0 and RA1) for voltage sensing, (ii) CCP module for generating PWM pulses to regulate the boost converter MOSFET, and (iii) GPIO pins for LCD interfacing. The firmware is written in PIC-C and programmed via PICkit.

E. Boost Converter Circuitry

A DC-DC boost converter steps up the solar panel output voltage for battery charging, operating at approximately 20 kHz. Circuit components include: inductor L = 470 μH, capacitor C = 1000 μF/25V, 1N4007 freewheeling diode, and IRF540N MOSFET switch. The MPPT duty cycle is continuously adjusted to maintain operation near the MPP. The voltage gain in continuous conduction mode (CCM) is:

$V\_out / V\_in = 1 / (1 - D)$

where D is the duty cycle ($0 < D < 1$). For a typical input of 12V and desired output of 13–14V for charging, a duty cycle of approximately 10–15% is required.

F. LCD Display and Indicators

A 16×2 LCD display, interfaced with the PIC microcontroller, continuously shows the solar panel input and battery output voltages. Two status LEDs connected to PIN_C4 and PIN_C5 provide system initialization indication.

III. MPPT ALGORITHMS

A. Perturb and Observe (P&O)

The Perturb and Observe algorithm is widely used due to its simple operating principle and minimal hardware requirements. The algorithm periodically perturbs the PV module's operating voltage by incrementing or decrementing the PWM duty cycle and observes the resulting change in output power.

Decision rules: if a positive perturbation results in increased power ($\Delta P > 0$), the perturbation direction is maintained; otherwise, the direction is reversed. The process repeats continuously, causing the operating point to oscillate around the MPP.

Limitations of P&O include: (i) continuous steady-state oscillation around the MPP causing energy losses, (ii) mistracking under rapid irradiance changes, and (iii) inability to distinguish global and local MPPs under partial shading, often converging to a local optimum [1], [5].

B. Particle Swarm Optimization (PSO)

PSO is a meta-heuristic algorithm inspired by the social behavior of bird flocking. In MPPT applications, each particle represents a possible duty cycle value, and the swarm collectively explores the P-V curve to find the global MPP. At each iteration, each particle i updates its velocity and position as:

$$v\_i(k+1) = w \cdot v\_i(k) + c_1 \cdot r_1 \cdot [pbest\_i - x\_i(k)] + c_2 \cdot r_2 \cdot [gbest - x\_i(k)]$$

$$x\_i(k+1) = x\_i(k) + v\_i(k+1)$$

where w is the inertia weight, c_1 and c_2 are acceleration coefficients (set to 2.0), r_1 and r_2 are random numbers in [0,1], pbest_i is the personal best position, and gbest is the global best position. Parameters used: N = 5 particles, w decreasing from 0.9 to 0.4, maximum iterations = 20.

IV. MATLAB/SIMULINK SIMULATION

A. PV Panel Model

A 50W PV panel model was developed in MATLAB/Simulink using the single-diode equivalent circuit. Model parameters: I_sc = 3.17 A, V_oc = 21.1 V, V_mpp = 17.4 V, I_mpp = 2.87 A, TcI_sc = 0.065%/°C.

B. P&O Simulation — Uniform Irradiance

The P&O simulation was conducted at 1000 W/m² irradiance, 25°C. Boost converter parameters: L = 2 mH, C = 470 μF, switching frequency = 25 kHz. The system successfully tracks the MPP at ~50W. At steady state, output power oscillates within ±1.5W of the MPP due to the perturbation step size $\Delta D = 0.005$. When irradiance drops from 1000 W/m² to 500 W/m² at t = 0.1 s, the P&O algorithm re-tracks the new MPP within approximately 0.2 seconds.

C. PSO Simulation — Partial Shading Conditions

Partial shading was simulated using a 3-panel array configuration: Panel 1 at 1000 W/m², Panel 2 at 600 W/m², and Panel 3 at 300 W/m². This configuration generates a P-V curve with multiple peaks—a local maximum near 11W and a global maximum near 28W.

In 3 out of 5 random starting positions, the P&O algorithm converged to the local maximum, resulting in significant energy loss. In contrast, the PSO algorithm consistently identified the global maximum in all test cases within 15 iterations.

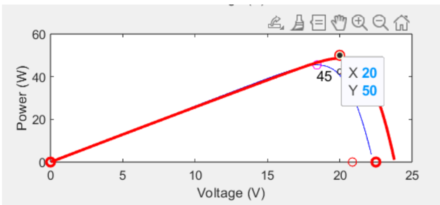

Fig. 2: P-V characteristics under partial shading — comparison of P&O vs PSO tracking

V. HARDWARE RESULTS

The hardware prototype was tested under varying outdoor illumination conditions over a single day. Table I presents the measured performance data at different irradiance levels.

TABLE I: Hardware Measurement Results Under Varying Irradiance

Test Condition	Irradiance (W/m²)	Panel Voltage (V)	Duty Cycle (%)	Output Voltage (V)
Full Sun	1000	12.4	72	12.9
Partial Shade	600	10.1	68	12.6
Low Irradiance	300	7.8	61	12.2
Overcast	150	5.5	52	11.8

Table I: Measured solar panel voltage, duty cycle, and output voltage under different conditions

The LCD display provided accurate voltage readings with ±0.1V error. The system maintained stable charging with no abrupt duty cycle changes even during gradual irradiance variations. Under full sun (1000 W/m²), the solar panel generated 12.4V, and the boost converter produced 12.9V at the battery terminals—sufficient for float charging a 12V lead-acid battery.

VI. COMPARATIVE ANALYSIS: P&O VS PSO

Table II summarizes the performance comparison between P&O and PSO based on simulation results and analytical evaluation.

TABLE II: Performance Comparison of P&O and PSO MPPT Algorithms

Parameter	P&O Algorithm	PSO Algorithm	Advantage
Tracking Speed	Moderate	Fast	PSO
Partial Shading	Poor	Excellent	PSO
Oscillations at MPP	Present	Minimal	PSO
Computational Load	Low	Medium	P&O
Convergence	Local Optima	Global Optima	PSO
Efficiency (%)	~88%	~95%	PSO

The results confirm that PSO outperforms P&O in partially shaded PV systems due to its global optimization capability. Nevertheless, for standalone solar PV systems operating under consistent illumination conditions (such as the 12V, 3W hardware prototype), P&O remains a viable choice owing to its simplicity and proven real-world efficiency.

VII. DISCUSSION

The developed hardware successfully demonstrates MPPT implementation on a low-cost 8-bit microcontroller. The PIC16F72's 10-bit ADC provides adequate voltage resolution (~4.9 mV/LSB with a 5V reference), and the integrated CCP peripheral enables precise PWM generation without additional hardware.

Simulation results indicate that selection of the appropriate MPPT technique depends on PV system operating conditions. For single-panel or non-shaded arrays (such as open rooftops or agricultural installations), P&O is recommended due to its simplicity and proven efficiency. For large urban PV arrays susceptible to shading from adjacent buildings or structures, PSO or advanced optimization algorithms are preferred [4], [6].

A limitation of the current system is the fixed perturbation step size in the P&O algorithm. Implementing an adaptive perturbation amplitude—larger steps during transient conditions and smaller steps at steady state—would reduce oscillation losses and improve overall efficiency.

VIII. CONCLUSION

This work presents a combined experimental and simulation study of solar MPPT: hardware testing of a PIC16F72-based system with P&O MPPT and a boost DC-DC converter, alongside a comparative MATLAB/Simulink analysis of P&O and PSO algorithms under uniform and partial shading conditions.

Key findings are: (i) The hardware system successfully tracks the MPP in real time, maintaining output voltage within ±5% across varying irradiance levels. (ii) P&O performs reliably under uniform irradiance but fails under partial shading, converging to local MPPs and losing 30–40% of harvestable power. (iii) PSO achieves global MPP tracking with ~95% efficiency across all test scenarios. (iv) The low-cost PIC-based design is suitable for standalone rural solar charger applications.

Future work will focus on adaptive step-size P&O implementation, integration of PV module temperature sensing, and development of a streamlined PSO algorithm on a 32-bit microcontroller (STM32).

ACKNOWLEDGMENT

The authors would like to thank the Department of Electrical and Electronics Engineering, GPREC, Kurnool, for providing laboratory facilities and resources to support this research work.

REFERENCES

[1] T. Esram and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," IEEE Trans. Energy Convers., vol. 22, no. 2, pp. 439–449, June 2007.

[2] D. P. Hohm and M. E. Ropp, "Comparative Study of Maximum Power Point Tracking Algorithms," Prog. Photovolt.: Res. Appl., vol. 11, no. 1, pp. 47–62, Jan. 2003.

[3] K. Ishaque and Z. Salam, "A Review of Maximum Power Point Tracking Techniques of PV System for Uniform Insolation and Partial Shading Condition," Renew. Sustain. Energy Rev., vol. 19, pp. 475–488, Mar. 2013.

[4] M. Miyatake, M. Veerachary, F. Toriumi, N. Fujii, and H. Ko, "Maximum Power Point Tracking of Multiple Photovoltaic Arrays: A PSO Approach," IEEE Trans. Aerosp. Electron. Syst., vol. 47, no. 1, pp. 367–380, 2011.

[5] K. L. Lian, J. H. Jhang, and I. S. Tian, "A Maximum Power Point Tracking Method Based on Perturb-and-Observe Combined with Particle Swarm Optimization," IEEE J. Photovolt., vol. 4, no. 2, pp. 626–633, 2014.

[6] N. A. Ahmed and M. Miyatake, "A Novel Maximum Power Point Tracking for Photovoltaic Applications under Partially Shaded Insolation Conditions," Electr. Power Syst. Res., vol. 78, no. 5, pp. 777–784, 2008.

[7] Microchip Technology Inc., "PIC16F72 Data Sheet," DS30221C, 2002. [Online]. Available: http://www.microchip.com

[8] M. A. G. de Brito, L. Galotto, L. P. Sampaio, G. de Azevedo e Melo, and C. A. Canesin, "Evaluation of the Main MPPT Techniques for Photovoltaic Applications," IEEE Trans. Ind. Electron., vol. 60, no. 3, pp. 1156–1167, Mar. 2013.