Implementation of a Modified PSO for MPPT Tracking in Partially Shaded PV Systems using PIC18F4550 in Proteus Software

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Abstract— **Partial shading conditions (PSCs) significantly degrade the efficiency of solar panels, which create numerous power peaks (local and global maximum points) on the P-V curve of the photovoltaic (PV) system due to bypass diodes in series modules. Classical maximum power point tracking (MPPT) methods often fail to distinguish the global maximum power point (GMPP) and direct the system towards getting stuck within local maxima, thereby decreasing overall power output. To tackle the partial shading issues of solar power systems, a Modified Particle Swarm Optimization (MPSO) algorithm has been developed to search for the global maximum power point (GMPP) more reliably, even when there is a complex shading pattern. The DC-DC boost converter and the resistive load are connected with the PV system while controlling the switching action with a PIC18F4550 microcontroller through applying PWM pulses based on the proposed optimization technique. To emulate and adjust the real hardware behavior at low cost, the PV modules, the Boost converter, and the MPPT algorithm were simulated and modelled using Proteus software. Experiments confirmed that the MPSO algorithm could follow the GMPP within 1.3 seconds on average, even when shading patterns changed, and it recorded an average of 99.5% efficiency. These findings indicate that the algorithm may overcome shading issues and approach maximum power levels with regularity. By combining both hardware simulation and emulation, the research confirms that this approach helps to study and develop MPPT algorithms that are applied to PV systems under partial shading conditions instead of real hardware in labs.**

Keywords— ***MPPT, Particle Swarm Optimization, Partial Shading, PIC18F4550, Proteus, PV Systems.***

I. INTRODUCTION

Solar energy is considered a sustainable solution for increasing global energy demand and offers a clean and renewable energy alternative to fossil fuels. Solar energy fights global warming, promotes energy independence, and saves on long-term expenditures, even with the high upfront costs. Palestine endowed with abundant solar resources which it has a huge potential for solar development. However, systemic barriers persist due to the prolonged occupation such as including movement and access restrictions in the West Bank, the blockade of Gaza, and external control of energy infrastructure. These barriers repress autonomous energy systems and perpetuate reliance on imported electricity [1]. Solar technology advancements in efficiency and cost-effectiveness enhance solar power transition, which is both a strategic and economic requirement to ensure Palestine's sustainable future. Improving solar system efficiency requires the development of innovative methods that optimize the conversion of solar energy to electrical energy and develop storage systems [2-4].

In photovoltaic (PV) systems, MPPT is crucial. Regardless of changes in environmental factors like temperature and sun irradiation, it performs the fundamental task of maximizing the energy produced by the solar panels. To keep the solar PV system running at its best during peak power, these methods continuously modify the system's operating voltage and current. Therefore, MPPT makes solar power systems more efficient and economically viable by greatly increasing the overall system efficiency and long-term energy expenses [5-8].

In photovoltaic systems, partial shading is a serious issue because it prevents sunlight from reaching solar panels, which lowers power generation, causes hot spots that degrade local cells, and obscures the true maximum power point (MPP) with multi-peaked power-voltage (P-V) characteristics [9]. In particular, PV panels that use parallel-connected bypass diodes make this situation worse by creating several local peaks in the current-voltage (I-V) curve, making it difficult to locate the global peak. Under partial shading situations, traditional MPPT algorithms like perturb and observe (P&O) [10], and incremental conductance (INC) [11] have difficulty differentiating these peaks and frequently fall short of achieving optimal power extraction. Artificial Neural Networks (ANN) [12] and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) [13] are two of the first AI-based MPPT approaches to address this issue. They use advanced computational techniques to track the global peak with various shading patterns. However, the models require massive amounts of data, a great deal of computing memory, and prior knowledge of photovoltaic systems. In some cases, the method can improve accuracy and performance despite these restrictions.

Furthermore, by tracking the global maximum power point (GMPP), metaheuristic algorithms like genetic algorithms (GA) [14], differential evolution (DE) [15], gray wolf optimization (GWO) [16], bat algorithms (BA) [17], particle swarm optimization (PSO) [18], artificial bee colony (ABC) [19], and ant colony optimization (ACO) [20], demonstrate great potential to improve power harvesting and system efficiency under partial shading conditions (PSCs). The

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efficiency, accuracy, tracking rate, and computing complexity of the metaheuristic algorithms vary, which is interesting since these factors influence how they are applied in particular MPPT applications under partial shade situations depending on the resource restrictions and desired performance.

Design and validation of Maximum Power Point Tracking (MPPT) algorithms are typically done in PSIM and MATLAB/Simulink environments [21]. Embedded boards and processors like FPGA, Arduino, PIC, or DSP cannot be interfaced by the aforementioned software tools needed for real prototype testing of MPPT algorithms [22]. Proteus stands out by offering electrical system simulations that include hardware components like microcontrollers such as PIC18F4550 and FPGAs, DSPs, embedded boards such as Arduino, sensors, and actuators to enhance debugging as well as minimize system errors. The Proteus platform previously did not support an internal photovoltaic (PV) panel model [23]. The research has a groundbreaking contribution by incorporating a single-diode photovoltaic (PV) model into Proteus through the use of a PIC microcontroller to facilitate maximum power point tracking (MPPT) under partial shading conditions. The new technique enhances the optimization of solar energy systems' performance in real life complex situations. Experimental validation through verification by researchers established that the modular blocks in Proteus are capable of seamlessly integrating both a PV module and an MPPT algorithm [24]. This innovation provides a low-cost PV emulator solution for those situations where physical prototyping becomes impractical because insufficient material assistance is not adequate or requisite electronic materials are unavailable. Political instability areas are plagued by these issues heavily in areas where disrupt educational facilities lead to reliance on web-based learning systems and simulation tools to continue academic studies.

This study explores the application of an improved PSO algorithm for MPPT tracking under partial shading conditions using the PIC18F4550 microcontroller simulated in Proteus software. The proposed improved PSO-based MPPT technique is intended to be simple yet highly effective, with significant enhancement over traditional methods. By decreasing the research time, the algorithm is computationally efficient and reduces memory usage, allowing it to be implemented on low-resource, inexpensive processors. This makes it especially appropriate for portable or small PV systems, where affordability is essential for wider adoption, particularly in areas with low economic standing.

II. Integration of SPICE-Based PV Panel Modeling in Proteus Environment and Analysis of PV System Under Partial Shading

A. *PV panel model characteristics using Proteus*

The photovoltaic (PV) module structure in Fig. 1 includes key components: a current source, diode (D), series resistance (R_s), and parallel shunt resistance (R_{sh}). This follows the single-diode equivalent circuit model that characterizes the PV cell's behavior. The output current of the PV cell is represented by Equation (1).

$$I_{pv} = I_{ph} - I_0 \times \left(exp\left(\frac{q\left(V_{pv} + R_s \times I_{pv}\right)}{\alpha kT} - 1 \right) \right) - \left(\frac{V_{pv} + R_s \times I_{pv}}{R_{sh}} \right) \quad (1)$$

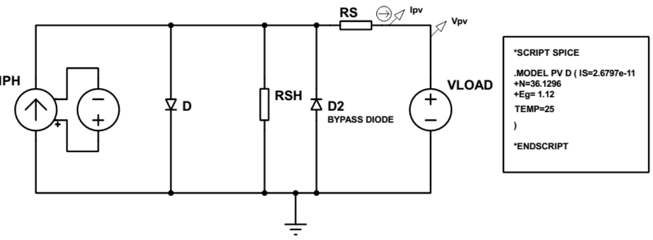


Figure 1. PV panel in Proteus model.

The TDC-M20-36 photovoltaic panel was selected for this study, with its technical specifications detailed in Table 1, following the methodology outlined in [24]. Fig. 2 illustrates the P-V and I-V characteristics of the panel, with a maximum power output of 20 W at approximately 18.7 V at STC, representing its maximum energy conversion efficiency. The PV panel model was also implemented using Proteus software, as illustrated in Fig. 1, to simulate and confirm its electrical performance.

TABLE I. Specification of TDC-M20-36 PV panel

Characteristics	Values
Maximum Power Point (MPP)	20 W
Voltage at MPP (V_{MPP})	18.76 V
Current at MPP (I_{MPP})	1.07 A
Short Circuit Current (I_{SC})	1.17 A
Open Circuit Voltage (V_{OC})	22.7 V

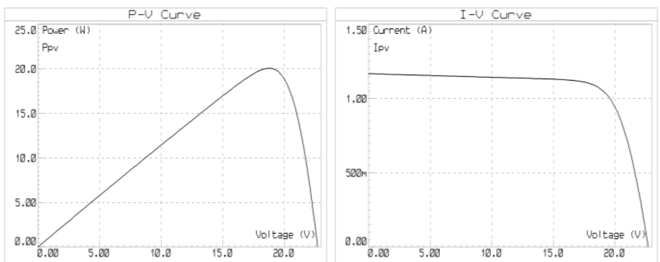


Figure 2. P-V and I-V characteristics of TDC-M20-36 PV panel using Proteus software

B. *The effects of Partial shading conditions on MPPT*

In photovoltaic (PV) systems, PV modules are interconnected in series or parallel to form arrays. Partial shading conditions (PSC), caused by factors like clouds, debris, or shadows, reduce the current and voltage of affected modules. This can force shaded modules to act as resistive loads rather than power generators, lowering the system's overall efficiency. To mitigate this, bypass diodes are integrated parallel to each module, enabling current to circumvent shaded regions and maintain power flow as shown in Fig. 3. Under uniform irradiation (Fig. 3-a), the P-V curve exhibits a single peak, and the I-V curve shows a smooth, consistent drop in current with increasing voltage, allowing the MPPT to easily locate the global maximum power point (GMPP) as shown in Fig. 4. In contrast, non-uniform irradiance (Fig. 3-b), caused by shading, creates multiple peaks in the P-V curve and steps in the I-V curve as shown in Fig. 5, which it introduces multiple local maximum power peaks (LMPPs) and a single global maximum power peak (GMPP) on these curves, complicating maximum power point tracking and it may mislead conventional MPPT algorithms. It should be noted here that all these plots, for both uniform and non-uniform irradiation radiation cases, were drawn and simulated using Proteus software.

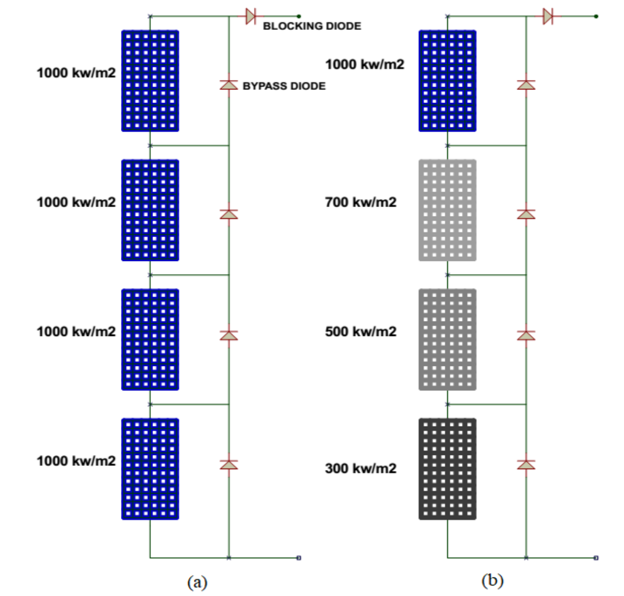


Figure 3. Two Modes for PV panels Irradiance: (a) uniform at 1000 W/m² vs. (b) non-uniform at 1000,700,500 and 300 W/m².

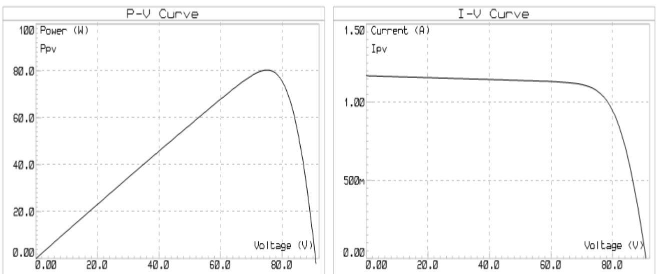


Figure 4. P-V and I-V characteristics for uniform irradiance PV panels in Figure 3-a using Proteus software

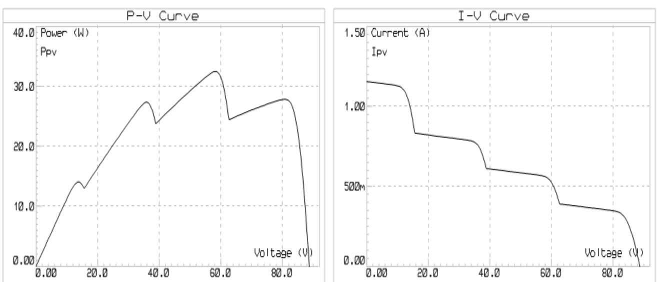


Figure 5. P-V and I-V characteristics for non-uniform irradiance PV panels in Figure 3-b using Proteus software

Bypass diodes, while reducing losses, exacerbate this complexity by creating multiple power peaks. Consequently, advanced MPPT algorithms are essential to dynamically track the GMPP, continuously adjusting the operating point to counteract shading effects. These controllers optimize energy harvest under varying irradiance, enhancing system resilience and performance.

III. MPPT Approach Based on Modified PSO

The PSO algorithm, introduced by Eberhart and Kennedy [25], is a population-based metaheuristic inspired by biological swarms, where particles representing candidate solutions navigate the search space to locate global optima. To integrate the modified PSO with a microcontroller to find MPPT, it needs the system initializes hardware components, including ADC ports for sensor acquisition, and PWM timer configuration for duty cycle modulation at a 5 kHz frequency.

In this paper, population size is initialized to 5, where five candidate solutions (particles) are initiated at predetermined duty ratios (20%, 40%, 60%, 80%, 85%), the maximum iteration is initialized to 20, and duty cycle boundaries are [0-100%]. This method promotes diversity, avoids clustering and premature convergence, and allows controlled experimentation via standardization of initial conditions for accelerating the identification of the global maximum power point under dynamic operating conditions by efficient parameter space exploration. The sample time is fixed at 20 ms between consecutive control updates, ensuring stable power measurements while being sensitive to environmental changes. Each of the candidates undergoes: Application of the duty cycle of PWM, Measurement of parameters of photovoltaic (voltage via ADC channel 0, current via ADC channel 1) Fitness calculation as electrical power (P = V × I). The initial global best position (g_{best}_position) is determined as the duty cycle for optimum power.

In standard PSO, each particle k at iteration (t) is characterized by two primary vectors: a position vector $x_k(t)$, which contains a potential solution, and a velocity vector $v_k(t)$, which indicates direction and magnitude of movement. In optimization, particles update their trajectories iteratively by balancing personal experience (guided by their own personal best solution, p_{best}) and social interaction (guided by the global best solution of the swarm, G_{best}). The velocity and position updates in standard PSO are provided as:

$$v_i(k+1) = \omega \times (v_i(k) + C_1 \times r_1 \times \left(P_{best,i} - X_i(k)\right) + C_2 \times r_2 \times (G_{best} - X_i(k))) \quad (2)$$

$$X_i(k+1) = X_i(k) + v_i(k+1) \quad (3)$$

Where: w: Inertia weight. c_1, c_2 : Cognitive and social coefficients r_1, r_2 are Random numbers ∈ [0,1].

The Modified Particle Swarm Optimization (PSO) addresses the problem of finding Maximum Power Point Tracking (MPPT) under partial shading conditions. By avoiding the explicit computation of velocity, the algorithm keeps computational complexity low by directly updating particle positions via leader influence and random terms as shown in Equation (4).

$$X_i(k+1) = X_i(k) + r_1 \times TF \times \left(G_{best} - X_i(k)\right) + r_2 \times \left(1 - \frac{k}{k_{max}}\right) \times \left(X_i(k) - G_{best}\right) \quad (4)$$

This simplification enables real-time operation on resource-constrained microcontrollers like the PIC18F4550. The algorithm further streamlines computation by removing personal best (p_{best}) tracking, relying solely on g_{best} for social guidance. This reduces memory usage by O(k) (for k particles), critical for embedded systems like the PIC18F4550 with limited RAM.

In addition, the Transition Factor ($TF = 2e^{-t/20}$), replaces classical PSO's linear inertia. TF decays exponentially, fostering early exploration ($TF \approx 2$) and shifting to exploitation ($TF \rightarrow 0$) over time. This eliminates manual inertia tuning while balancing exploration-exploitation trade-offs across irradiance variations. The flowchart of the modified PSO-based MPPT is illustrated in Fig. 6.

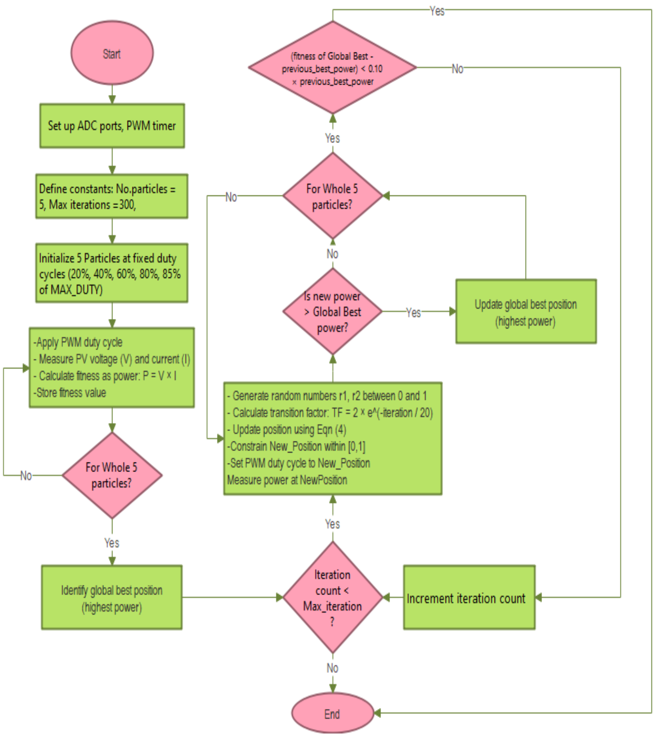


Figure 6. Flowchart of modified PSO-based MPPT

IV. Results and Discussion

The experimental validation of the proposed Modified PSO for MPPT is implemented through a boost converter-based the system setup, as depicted in Fig. 7. The DC-DC boost converter a critical function in this system, which is power transfer optimization, which is elaborated in this section. The particle positions map directly to DC-DC converter duty cycles. The PIC18F4550 executes ADC-based V_{PV} and I_{PV} sampling, PWM duty cycle adjustments (5 kHz). By reimagining PSO through swarm intelligence and embedded constraints, this work delivers a hardware-efficient MPPT solution. The removal of velocity vectors, dynamic boundaries, and adaptive TF collectively address classical PSO limitations, enabling rapid convergence under partial shading while maintaining compatibility with low-cost microcontrollers a significant advancement in renewable energy control systems.

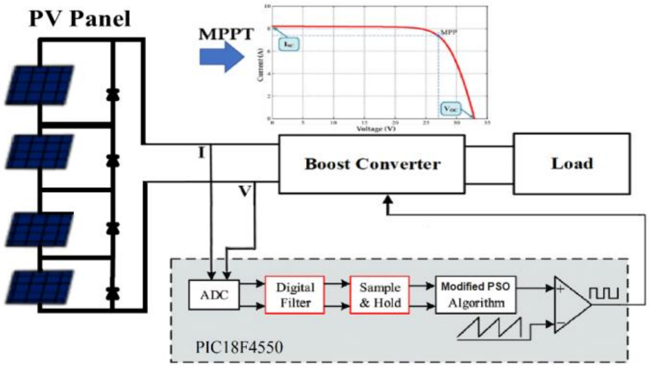


Figure 7. The system setup block diagram (Boost converter)

Fig. 8 illustrates a system designed for Maximum Power Point Tracking (MPPT) in a solar power system using Proteus simulation for validation the proposed method. The circuit comprises several key components working in concert to optimize energy extraction from solar panels. On the left side, solar panels are depicted, with four TDC-M20-36 PV panels connected in series. These panels serve as the primary energy source, converting solar irradiance into electrical energy. To ensure unidirectional current flow and prevent reverse current, a blocking diode is incorporated between the solar panels and the rest of the circuit. Furthermore, bypass diodes are paralleled between each solar panel so that current can be redirected around a shaded or failed panel, thereby saving power output from the other panels. The system employs an INA169 Analog DC Current Sensor to measure the current generated by the solar panels by detecting the voltage drop across an external shunt resistor placed in the current path (R5=0.1 ohm). In order to generate an analogue output voltage corresponding to the measured current, an inbuilt operational amplifier then amplifies this slight voltage drop. The sensor's operational amplifier (U1) and resistor (R6 = 50 k ohm) generate an analogue output proportionate to the current being measured. Using resistors (R3 = 25 k ohm and R4 = 400 k ohm) to lower the voltage to a level appropriate for microcontroller measurement, the B25 Voltage Sensor Module detects the voltage from the solar panel. The converter configuration employs the following parameters: input and output capacitors are C_{IN}=128µF, C_O=15 µF, an inductor L=114mh, and a load resistance R_{LOAD} =666 Ω. The MOSFET operates at a switching frequency of 5 kHz. The inductor (L), the most crucial component of the DC-DC converter circuit, stores energy in its magnetic field and releases it to control the output voltage and current. To eliminate ripples and provide a steady power source, input and output voltages are filtered using capacitors such as the input capacitor C_{IN} and the output capacitor C_O. A Pulse Width Modulation (PWM) signal sent through the microcontroller controls the MOSFET (Q1), the converter's switch element. To provide the necessary voltage and current to drive the MOSFET efficiently, a MOSFET driver (U2, TC4420 Driver) is used. When the MOSFET is turned off, a freewheeling diode (D4) is used to supply a path to the current. The electrical power powers the load (R_{LOAD}). The MPPT system's essential component is the microcontroller (U3, PIC18F4550). To optimize the power received from the solar panels, this unit measures the voltage and current readings from the corresponding sensors, applies the modified-PSO-based MPPT algorithm, and creates a 5 kHz PWM signal to regulate the MOSFET. Liquid crystal displays (LCD1, LM016L) provide useful information like voltage, current, or the MPPT system status. Finally, the PIC18F4550 microcontroller operates at 20MHz and it have 32KB flash memory and a 10-bit ADC enabling efficient real-time data processing, and its high-speed PWM enables dynamic control.

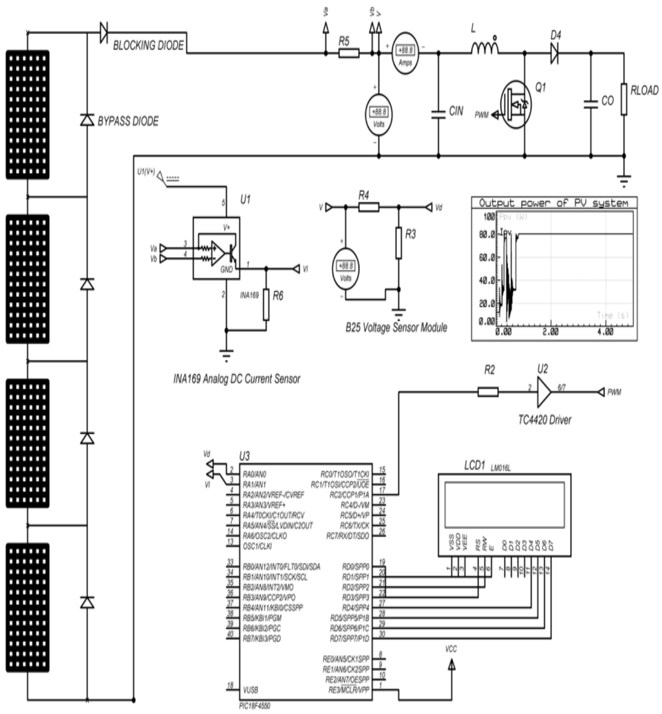


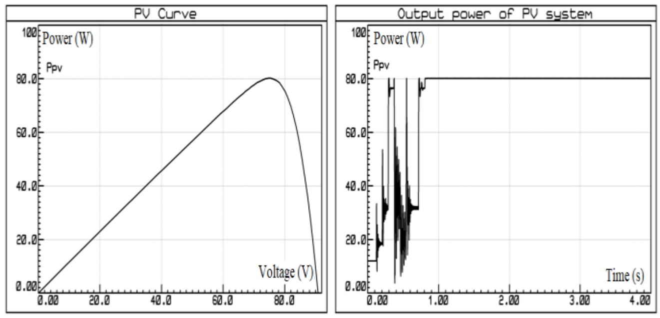
Figure 8. Experimental setup.

The efficiency for the MPPT method is calculated using equation (5).

$$MPPT_{efficiency} = \frac{Power\ of\ steady\ state}{Maximum\ power\ available} \times 100\% \quad (5)$$

A. Validation of MPPT proposed method under uniform irradiance

Fig. 9 displays the simulation results for the four PV panels at 1000 W/m² for the experimental configuration in Fig. 8. This circumstance made it possible to achieve a maximum extractable power of 80.2 W. The GMPP was successfully tracked in a remarkably short amount of time (0.9 seconds) with a very high MPPT tracking efficiency (99.80%). It is noteworthy that the application of the improved method shortens steady-state oscillations, as inferred from these graphical depictions. This observation demonstrates how the MPSO-MPPT approach improves performance by stopping all extra calculations, resulting in lower steady-state oscillations and faster tracking.



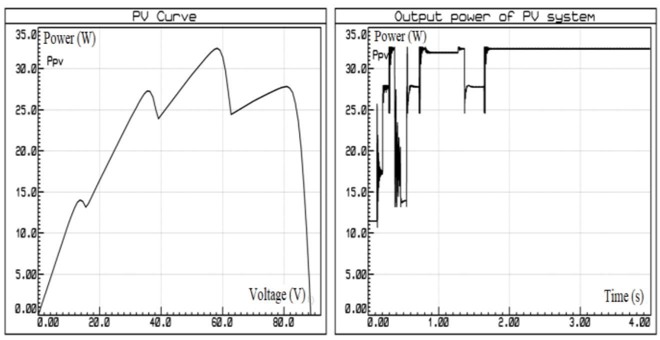
(a) (b)

Figure 9. Verification of the MPSO under 1000 W/m^2 uniform irradiance

B. Validation of the MPPT proposed method under various partial shading patterns

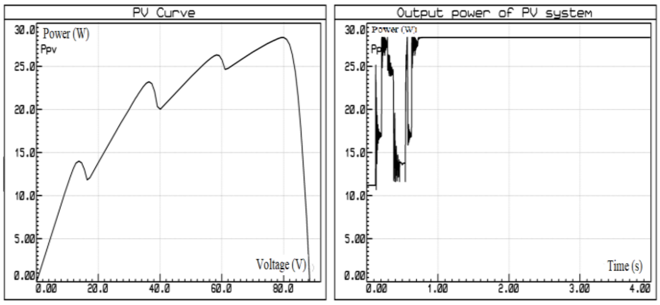
1. PSC-1: 1000, 500, 430, and 350 W/m^2
2. PSC-2: 1000, 600, 512, and 170 W/m^2
3. PSC-3: 170, 300, 940, and 85 W/m^2

In PSC-1, the solar panels were subjected to four levels of sunlight: 1000, 500, 430, and 350 W/m². Here, the GMPP was concealed between two small power peaks (LMPP), which makes it a tougher challenge. The tracking algorithm found this location in 1.8 seconds with 99.69% efficiency (computed from steady-state power in Fig.10.b and max power available, as shown in Fig. 10.a). In PSC-2, the arrangement was subjected to an array of 1000, 600, 512, and 170 W/m². The "golden zone" of highest power (GMPP) appeared on the far right of the curve. The system continued to steadily score 99.65% efficiency in 0.8 seconds (with Fig. 11's power values). In PSC-3, with extremely varying sunlight (170, 300, 940, and 85 W/m²), the "golden zone" of highest power (GMPP) appeared on the far left of the curve. the tracker locked onto the GMPP in just 1.6 seconds. Efficiency dropped slightly to 99.25% (derived from Fig. 12 (a) Pmax=13.3 W and from Fig 12 (b) steady-state power=13.2 W).



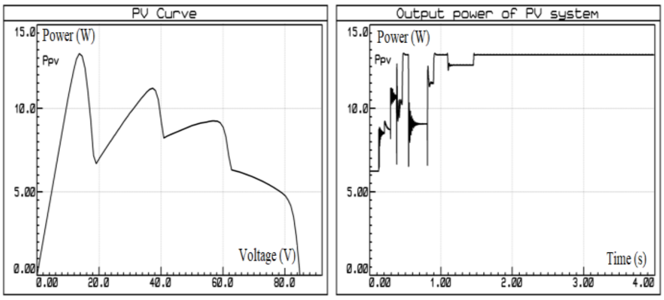
(a) (b)

Figure 10. Verification of the MPSO for PSC-1: (a) P-V curve. (b) The result of output power for the proposed method



(a) (b)

Figure 11. Verification of the MPSO for PSC-2: (a) P-V curve. (b) The result of output power for the proposed method



(a) (b)

Figure 12. Verification of the MPSO for PSC-3: (a) P-V curve. (b) The result of output power for the proposed method

V. CONCLUSION

Partial shading conditions (PSCs) degrade solar panel efficiency by creating multiple power peaks on photovoltaic (PV) systems' P-V curves, challenging conventional maximum power point tracking (MPPT) methods that often fail to locate the global maximum power point (GMPP). To address this, a modified Particle Swarm Optimization (MPSO)-based MPPT algorithm is proposed, leveraging adaptive transition factors to reliably identify the GMPP under diverse PSC patterns. The system integrates a DC-DC boost converter interfaced with a PIC18F4550 microcontroller, which generates precise PWM signals for switching regulation. By eliminating velocity vectors and personal best (p_{best}) tracking, the MPSO reduces computational overhead and memory usage (O(k) for k particles), enabling real-time operation on resource-constrained hardware. Proteus software simulation validation of the PV system, converter, and MPPT algorithm verifies the method's effectiveness. Experimental results show that the MPSO achieves an average tracking time of 1.3 seconds and 99.5% efficiency under various PSC conditions, outperforming conventional approaches. This work bridges simulation and hardware emulation, validating the MPSO's practicality for real PV installations. By combining swarm intelligence with embedded system constraints, the proposed solution mitigates partial shading effects, ensuring near-optimal power extraction. The integration of low-cost microcontrollers like the PIC18F4550 underscores its viability for scalable, energy-efficient renewable energy systems, advancing MPPT technology for real-world applications.

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