IJE TRANSACTIONS B: Applications Vol. 37 No. 08, (August 2024) 1569-1579

International Journal of Engineering

Journal Homepage: www.ije.ir

A New Modified Bacterial Foraging MPPT Technique with Dynamic Mutation Rates for Photovoltaic Systems under Partial Shading Conditions

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PAPER INFO

Paper history:
Received 13 December 2023
Received in revised form 30 December 2023
Accepted 22 January 2024

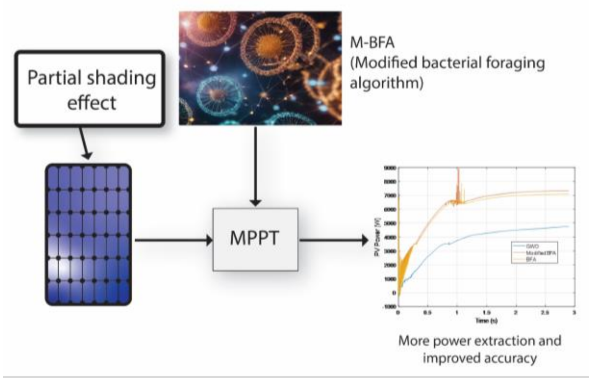
Keywords:
Photovoltaic Systems
Maximum Power Point Tracking
Partial Shading
Bacterial Foraging Algorithm
Grey wolf optimization
Dynamic Mutation Rate

ABSTRACT

This research article presents a novel approach to Maximum Power Point Tracking (MPPT) for photovoltaic systems, employing a modified bacterial foraging algorithm with dynamically adjustable mutation rates. This method is specifically tailored to address the challenges presented by partial shading conditions, ensuring efficient and rapid tracking of the MPP while preventing local optima entrapment. To evaluate the performance of this innovative technique, a comparative analysis is conducted against the original bacterial foraging algorithm and the grey wolf optimization algorithm, both commonly employed in MPPT applications. The modified algorithm incorporates a unique strategy that dynamically adapts mutation rates based on the algorithm's convergence behavior, enhancing the tracking accuracy from 81.31% to 89.39%. To validate the effectiveness of the proposed technique, extensive simulations are carried out using MATLAB Simulink, considering various partial shading scenarios commonly encountered in practical photovoltaic applications. It's worth noting that the shading scenario data were extracted from the NASA Worldwide Prediction of Energy website, specifically from the city of Ain El Ibel Djelfa irradiance records. The simulation results unequivocally demonstrate the superiority of the modified bacterial foraging MPPT technique over both algorithms in terms of tracking efficiency (0.4s to 0.9s) and robustness under partial shading conditions. The findings of this research offer valuable insights into the potential advantages of employing a modified bacterial foraging approach for MPPT applications. This innovative techniques with its ability significantly enhance its performance in real-world scenarios involving partial shading, positioning it as a promising choice for optimizing photovoltaic system efficiency and power output.

doi*: 10.5829/ije.2024.37.08b.10*

Graphical Abstract



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Please cite this article as: Fergani O, Mechgoug R, Afulay Bouzid A, Tkouti N, Mazari A. A New Modified Bacterial Foraging MPPT Technique with Dynamic Mutation Rates for Photovoltaic Systems under Partial Shading Conditions. International Journal of Engineering, Transactions B*:* Applications. 2024;37(08):1569-79.

NOMENCLATURE			
Gen_{max}	The maximum number of generations	n	The diode ideality factor (typically around 1.2 to 2)
I_{pv}	The light-generated current	V	The voltage across the PV cell
I_s	The reverse saturation current	**Greek Symbols**	
R_p	The shunt resistance	μ_{max}	The maximum mutation rate
R_s	The series resistance	μ_{min}	The minimum mutation rate
I	The output current of the PV cell.		

1. INTRODUCTION

Solar photovoltaic (PV) systems have emerged as a promising and sustainable avenue for generating electricity from renewable energy sources. Ensuring the cost-effectiveness and widespread adoption of these PV systems hinges on the efficient extraction of energy (1, 2). Achieving this optimization mandate demands the implementation of effective Maximum Power Point Tracking (MPPT) algorithms, which continuously operate solar panels at their maximum power point (MPP) amidst fluctuating environmental conditions (3, 4).

While traditional MPPT algorithms like Perturb and Observe (P&O) and Incremental Conductance (IncCond) techniques have proven their mettle in uniform irradiance settings, they grapple with real-world complexities, especially in the face of partial shading events (5). Such shading scenarios introduce multiple local MPPs, confounding conventional algorithms in their quest to pinpoint the true MPP with precision. Consequently, suboptimal energy extraction and system performance are inevitable outcomes (6, 7).

To transcend these limitations and elevate the efficiency of PV systems operating under partial shading conditions, this research article introduces an inventive MPPT technique grounded in a modified bacterial foraging algorithm with dynamic mutation rate adaptation. The central thrust of this study revolves around the creation of an interactive and adaptive optimization framework proficient in steadfastly tracking the MPP under varying environmental dynamics, with a particular emphasis on partial shading scenarios.

The burgeoning growth of PV system installations necessitates the development of advanced MPPT methodologies endowed with adaptability and precision across diverse conditions (8, 9). In addressing this research conundrum, the proposed modified bacterial foraging algorithm introduces dynamic mutation rate adjustment, enabling the algorithm to deftly strike a balance between exploration and exploitation throughout the optimization journey.

The research pursuits encompass three primary dimensions: Firstly, the introduction of the groundbreaking modified bacterial foraging algorithm with dynamic mutation rate adaptation for MPPT in PV systems. Secondly, a comprehensive comparative investigation is undertaken, juxtaposing the performance of the proposed modified technique against both the original bacterial foraging algorithm and the grey wolf optimization algorithm under the aegis of partial shading conditions. Finally, the assessment of the modified algorithm's adaptability and resilience in precisely tracking the MPP while adroitly sidestepping local optima.

To fulfill these aspirations, an exhaustive suite of simulations is meticulously executed using MATLAB Simulink, underpinned by an array of partial shading scenarios mirroring the complexities of real-world operational settings. The simulations meticulously scrutinize the performance metrics of each algorithm, encompassing tracking accuracy, convergence dynamics, and overall efficiency.

The discernments gleaned from these simulations incontrovertibly establish the ascendancy of the proposed modified bacterial foraging MPPT technique over both the original bacterial foraging and grey wolf optimization algorithms when confronted with partial shading challenges. The dynamic mutation rate adjustment confers augmented exploration capabilities upon the algorithm, equipping it to liberate itself from the clutches of local optima and faithfully converge upon the true MPP.

The seminal contribution of this research resides in the innovation and adaptation of an MPPT technique tailored for PV systems navigating the intricacies of partial shading conditions. The proposed modified bacterial foraging algorithm, bolstered by dynamic mutation rate adaptation, augurs a promising path towards fortifying the efficiency and energy-harvesting prowess of PV systems. Its adaptiveness and robustness lay the foundation for more effective and sustainable PV systems, thus advancing the frontiers of renewable energy technologies.

2. PV SYSTEM

The PV system that has been studied in this article represented in Figure 1.

2. 1. Model of The CDFIG

Photovoltaic (PV) cell modeling involves mathematical equations that describe the behavior of the PV cell under varying conditions (10). The most widely used model for PV cells is the single-diode model, which provides a simplified representation

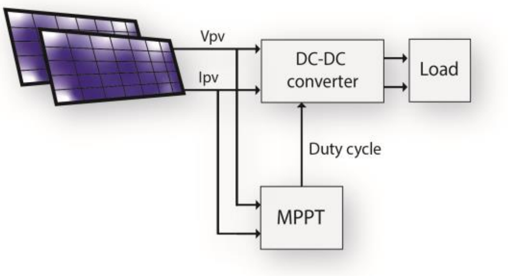

Figure 1. PV system

of the complex physical processes occurring within the cell (11). This model helps researchers and engineers predict the electrical characteristics of PV cells and design efficient PV systems (12), as illustrated in Figure 2.

The I-V relationship in a PV cell can be described using the single-diode Equation 3:

$$I = I = I_{pv} - I_S\left(e^{\frac{q(V+RsI)}{NsKta}} - 1\right) - \frac{V+RsI}{Rp} \quad (1)$$

Light-Generated Current : This represents the current generated by the incident sunlight. It depends on factors such as the intensity of light and the cell's efficiency in converting light to electricity.

Reverse Saturation Current: This term accounts for the leakage current through the diode even when it's reverse-biased. It's a crucial parameter that affects the cell's behavior under various conditions.

Series Resistance: This resistance represents the resistive losses in the cell's electrical connections and intrinsic resistance. It can lead to voltage drops across the cell.

Diode Ideality Factor: The ideality factor reflects the departure of the diode's behavior from the ideal Shockley diode equation. It accounts for recombination losses and non-idealities in the diode's behavior.

Thermal Voltage: The thermal voltage is related to the cell's temperature. It affects the behavior of the diode as the temperature changes.

Shunt Resistance: The shunt resistance represents paths for current to bypass the diode. It influences the cell's behavior under different illumination levels.

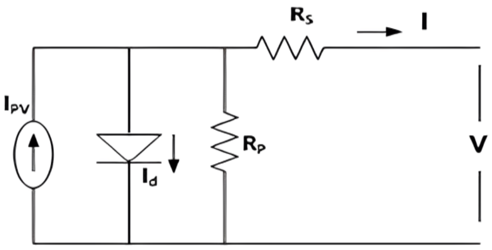

Figure 2. PV cell modeling

strings and 2 Series-connected modules per string. Table 1 provides detailed parameters of the used PV module of type 1Soltech 1STH-215-P with 20 Parallel

2. 2. Model Assumptions

The single-diode model simplifies the complex physical processes occurring in a PV cell. It assumes that the PV cell behaves like a single diode in parallel with a current source (13, 14). While this model provides a good approximation for many practical scenarios, it does not capture all the intricate phenomena happening within the cell (15).

2. 3. Practical Use

The single-diode model is valuable for designing PV systems, analyzing their performance, and predicting the cell's behavior under various conditions (16). Researchers and engineers can use this model to optimize system components, predict energy output, and develop control strategies for MPPT algorithms (17).

3. PARTIAL SHADING EFFECTS

3. 1. Partial Shading and its Effects on Photovoltaic Systems

Partial shading is a phenomenon that occurs when some portion of a photovoltaic (PV) module or array is shaded while other parts remain under direct sunlight (18) as shown in Figure 3. This shading can be caused by various factors such as nearby obstacles, trees, buildings, or even clouds passing over the PV installation (19). Despite its seemingly localized impact, partial shading can have significant effects on the performance and efficiency of PV systems, leading to non-uniform power generation, increased losses, and operational challenges (20). Understanding the intricacies of partial shading and its effects is essential for designing, optimizing, and managing efficient PV systems.

Non-Uniform Illumination: Partial shading causes non-uniform illumination across the PV module or array. As a result, different regions of the module experience varying levels of solar irradiance (21). This variation in irradiance leads to different operating points within the module, creating multiple maximum power points (MPPs) (22). Consequently, the module may operate far from its global MPP, reducing its overall energy output.

TABLE 1. PV Module parameters

Module data	Value
Maximum Power (W)	213.5
Open Circuit Voltage Voc (V)	36.3
Short Circuit Current Isc (A)	7.84
Maximum Voltage Vmax(V)	29
Maximum Current Imax(A)	7.35

Figure 3. PV partial shading

Hot Spots and Bypass Diodes: When a portion of a PV module is shaded, it acts as a barrier to the flow of current. The unshaded cells connected in series with the shaded cells generate excess voltage (23). This can result in 'hot spots,' where localized heating occurs due to the overvoltage, potentially leading to cell degradation or even module failure (24). To mitigate this issue, modern PV modules are equipped with bypass diodes that allow current to bypass shaded sections, preventing hot spot formation (25).

Mismatch Losses: Partial shading introduces mismatch losses, as shaded cells exhibit different current-voltage characteristics compared to unshaded cells (26). This mismatch can lead to significant power losses in the affected section of the module. These losses are particularly pronounced in traditional string configurations, where all cells are connected in series, making the weakest cell dictate the performance of the entire string (27).

Multiple MPPs and Tracking Challenges: Partial shading complicates the operation of Maximum Power Point Tracking (MPPT) algorithms. The presence of multiple MPPs requires sophisticated MPPT algorithms capable of rapidly adapting to changing conditions and dynamically selecting the correct MPP (18). Conventional MPPT algorithms often struggle to identify the global MPP under partial shading, leading to suboptimal energy harvesting (5).

Shading Patterns and System Design: Different shading patterns can have varying impacts on system performance. Series-connected modules are highly susceptible to shading effects, as the current of the entire string is determined by the weakest module (28). Parallel-connected modules fare better in partial shading scenarios as the current from unshaded modules is not affected by shaded modules. Optimizing system design, including module layout and array configuration, can help minimize the impact of shading (29).

Mitigation Strategies: Several strategies can mitigate the adverse effects of partial shading. These include using module-level power electronics, like microinverters or DC optimizers, which enable individual module-level MPPT. Additionally, more advanced MPPT algorithms that can handle multiple MPPs are essential. Bypass diodes and reconfiguration of module connections can also help minimize mismatch losses (18).

4. DC-DC BOOST CONVERTER MODELING

4. 1. Modeling of a DC-DC Boost Converter A DC-DC boost converter is a fundamental power electronic device used to step up a DC voltage level to a higher value (30). It plays a crucial role in various applications, such as renewable energy systems, electric vehicles, and battery charging, where voltage conversion and regulation are essential (30). Modeling a boost converter involves understanding its operating principles, components, and mathematical equations that describe its behavior. Here, we'll delve into the details of modeling a DC-DC boost converter (31), Figure 4 represent the electrical circuit of DC-DC Boost converter.

4. 2. Operating Principle A boost converter consists of key components, including a switch (usually a transistor), an inductor, a diode, and a capacitor. When the switch is turned on, the inductor stores energy from the input source (Vin), and when the switch is turned off, the inductor discharges its stored energy to the output capacitor (Vout) (32). The diode prevents reverse current flow. This cyclical process leads to voltage stepping up at the output (32).

4. 3. Operating Principle The basic equations governing the behavior of a boost converter can be described during two operating modes: the on-state (switch closed) and the off-state (switch open). The idealized model assumes no losses, which simplifies the equations (33).

On-State Equations: During the on-state, the inductor current ramps up, and the output voltage is mainly determined by the input voltage and the inductor current as both illustrated in Figure 5.

The relation between the input and the output of a SHLNN is given by Rahmani et al. (34):

$$V_{in} = V_L + V_o \tag{2}$$

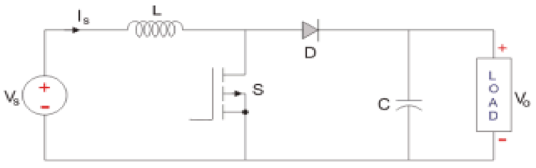

Figure 4. DC-DC Boost Converter

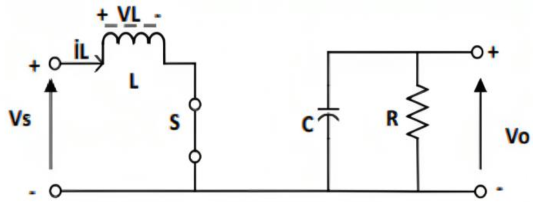

Figure 5. On-State Switch

Off-State Equations: During the off-state, the inductor discharges its energy into the output capacitor and load as shown in Figure 6.

$$V_o = -L.\frac{di}{dt} \tag{3}$$

The inductor current change $\left(\frac{di}{dt}\right)$ can be estimated using the following equation:

$$\frac{di}{dt} = \frac{V_{in} - V_o}{L} \tag{4}$$

4. 4. Non-Idealities Real-world boost converters have non-ideal characteristics that impact their behavior. These include switch and diode losses, inductor and capacitor parasitics, and voltage drops due to the internal resistance of components (35). Accounting for these non-idealities is crucial for accurate modeling.

4. 5. Control Strategies The performance of a boost converter can be improved through control strategies. Pulse Width Modulation (PWM) is commonly used, where the switch is turned on and off at a high frequency. The duty cycle of the switch controls the average output voltage (18).

4. 6. Small-Signal Modeling To analyze the dynamic behavior of a boost converter, small-signal modeling can be employed. This involves linearizing the equations around an operating point. Small-signal analysis helps understand stability, transient response, and design of control loops (36).

4. 7. Simulation and Practical Considerations Simulation tools like MATLAB/Simulink and SPICE are used to simulate and validate boost converter models. Practical aspects like component tolerances, switching frequency, and control loop dynamics must be considered for real-world implementation (1).

5. THE PROPOSED ALGORITHM

5. 1. Proposed Modified Bacterial Foraging Algorithm with Dynamic Mutation The modified bacterial foraging algorithm with dynamic mutation is an innovative optimization technique designed to enhance the efficiency of maximum power point tracking (MPPT) in photovoltaic systems, particularly under challenging conditions like partial shading. This algorithm introduces a dynamic mutation rate adjustment strategy to improve exploration and exploitation of the solution space. Let's delve into the details of this algorithm, including mathematical equations and a pseudo code.

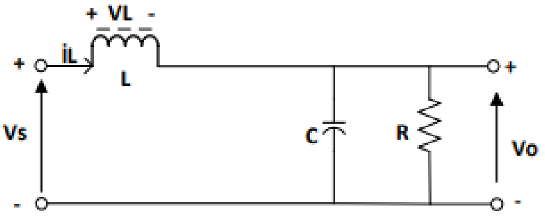

Figure 6. Off-State Switch

5. 2. Bacterial Foraging Algorithm Overview The bacterial foraging algorithm is inspired by the foraging behavior of bacteria to find food sources. It involves bacteria (agents) moving through a solution space, splitting, interacting, and evolving based on chemo tactic, reproduction, and elimination-dispersal processes (25).

5. 3. Dynamic Mutation Rate Adjustment In the proposed modification, the traditional bacterial foraging algorithm is enhanced by introducing a dynamic mutation rate adjustment mechanism. The mutation rate influences the randomness of bacteria movement, striking a balance between exploration and exploitation.

5. 4. Mathematical Equations The dynamic mutation rate (μ) is adjusted based on the convergence behavior of the algorithm. Initially, higher mutation rates promote exploration:

$$\mu = \mu_{max} \tag{5}$$

As the algorithm progresses towards the MPP, mutation rates are reduced to facilitate exploitation:

$$\mu = \mu_{max} - \frac{\mu_{max} - \mu_{min}}{Gen_{max}}.Gen \tag{6}$$

5. 5. Pseudo code of the Proposed Algorithm The proposed modified bacterial foraging algorithm with dynamic mutation can be summarized in the following pseudo code:

In the step of evaluating fitness of bacteria, each bacterium (which represents a potential solution to the optimization problem) is assessed based on a predefined fitness function. The fitness function is problem-specific and is designed to quantify how good a solution is in relation to the optimization goals. For example, in an optimization problem aiming to minimize energy consumption, lower energy consumption would correspond to higher fitness.

5. 6. Application to MPPT In the context of MPPT for photovoltaic systems, the algorithm's objective is to converge towards the global MPP despite partial shading conditions. The dynamic mutation rate adjustment allows for effective exploration early in the optimization process and targeted exploitation as the algorithm approaches the MPP region, enhancing the tracking efficiency.

The key Contributions of the proposed algorithm are presented in Table 2.

```
Start
Initialize bacteria population
Initialize generation counter (Gen = 0)
Initialize mutation rate ($\mu = \mu_{max}$)
Repeat until convergence or maximum generations:
    Evaluate fitness of bacteria
    Sort bacteria based on fitness
    Perform chemotaxis:
        For each bacterium:
            Randomly adjust position with mutation
            If fitness improves, accept new position
    Reproduction:
        Create new bacteria based on the successful ones
    Elimination-dispersal:
        Eliminate bacteria based on fitness
        Introduce new bacteria in empty spaces
    Update mutation rate (μ) based on dynamic adjustment equation
    Increment generation counter (Gen)
End
Stop
```

Figure 7. Pseudo Code of M-BFA Algorithm

TABLE 2. Key Contributions of the Proposed Algorithm

Existing Issues from Literature	Key Contributions of Proposed Modified Algorithm
Conventional MPPT algorithms struggle under partial shading conditions, leading to suboptimal energy extraction.	Introduces a modified bacterial foraging algorithm with dynamic mutation rate adjustment.
Multiple local MPPs arise due to partial shading, making accurate MPP identification challenging.	Dynamically adjusts mutation rates based on the convergence behavior to balance exploration and exploitation.
Shading patterns cause mismatch losses, reducing the overall system efficiency	Enhances tracking accuracy by gradually reducing mutation rates near the MPP, promoting exploitation.
Existing MPPT algorithms fail to rapidly adapt to changing conditions and handle multiple MPPs under shading	Improves efficiency and energy harvesting by enabling robust tracking and accurate MPP selection.
Challenges in designing efficient PV systems under partial shading conditions	Enhances adaptability of MPPT algorithm under varying and challenging operating scenarios

6. SIMULATION AND RESULTS DISCUSSION

To evaluate the performance of the proposed modified bacterial foraging algorithm with dynamic mutation (M-BFA) for maximum power point tracking (MPPT) in photovoltaic (PV) systems, extensive simulations were conducted using MATLAB Simulink. The simulation setup involved a PV system consisting of three PV panels under three different shading scenarios, reflecting real-world scenarios where partial shading can occur. The objective was to assess the algorithm's effectiveness in accurately tracking the maximum power point (MPP) and compare it with conventional MPPT techniques.

6. 1. Application to MPPT

The PV system comprised three identical PV panels connected in series, each array consists of 20 parallel strings and 2 series connected modules per string. Each panel was modeled using the single-diode model, capturing its electrical characteristics. The dynamic mutation rate (μ) was adjusted based on the algorithm's convergence behavior, as described earlier. Figure 8 represent the Simulink model of the system.

6. 2. Shading Scenarios

Three shading scenarios were simulated to represent different levels of partial shading presented in Table 3 are extracted from NASA worldwide power prediction website of city Ain Ibel Djelfa Algeria, Ain Ibel, Djelfa, like many places in Algeria, likely experiences a range of climatic conditions and solar irradiance patterns which can affect PV performance. This kind of environment is ideal for testing new algorithms because:

- It presents a challenge with its high variability in solar irradiance.
- It provides an opportunity to optimize energy yield in a region where solar energy can be a significant renewable resource.
- It may have unique local conditions (such as sandstorms or high temperatures) that can affect PV performance, and which an algorithm can learn to negotiate.

Therefore, these scenarios can provide comprehensive and challenging conditions for validating the performance and resilience of a new modified bacterial foraging algorithm, ensuring it is well-suited for optimizing PV systems in similar environments (37). These scenarios can be considered excellent for testing new modified algorithms for several reasons:

1. **Variability in Irradiance:** The different irradiance levels represent the real-world variability in sunlight due to factors like time of

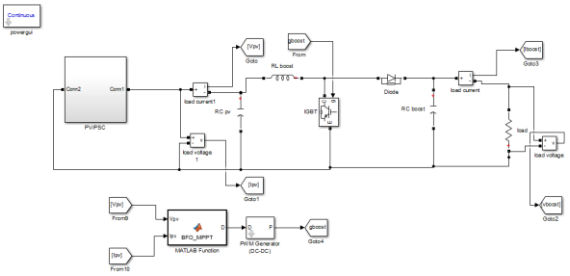

Figure 1. Simulink model of the system

day, weather, and seasonal changes. This variability is critical for testing the robustness of algorithms designed to optimize PV system performance.

2. **Shading Effects:** By providing irradiance levels for three different PV modules, it's implied that partial shading conditions can be simulated. Shading is a common issue for PV systems, and an algorithm that can adapt to shading will be more effective.
3. **Position Sensitivity:** The inclusion of position (Right, Middle) suggests the tests account for the directional impact on irradiance, which can be caused by the sun's angle or shadows from nearby objects. This helps in assessing the algorithm's ability to optimize panel orientation.
4. **Maximum Power Output:** The Max Power column indicates the peak power output achievable under the given conditions. This is useful for evaluating how close the algorithm can get to the theoretical maximum, which is a measure of efficiency.
5. **Real-world Data:** The data from NASA's worldwide power prediction website adds authenticity and practical relevance to the test cases. Using real data from a specific location like Ain Ibel, Djelfa in Algeria ensures that the algorithm is being tested under realistic conditions that are specific to that geographic area.

6. 3. Simulation Results

The simulation results revealed significant improvements in tracking efficiency and robustness using the proposed M-BFA algorithm compared to conventional MPPT techniques under partial shading scenarios. The algorithm demonstrated the following outcomes:

First test: The first test consists of high power of 9100 W in the right position with different values of irradiance close to each other to test the sensitivity of proposed techniques against the other two techniques, The P-V characteristics and the results of Power, Voltage and Current are shown in Figures 9, 10, 11 and 12.

Second Test: the Second test consists of maximum Power of 6600 W in the middle position, in this test the right local optimal power point and the middle one are closed to each to test the robustness of the proposed algorithm and its ability to find the true global optimal power point, the results are illustrated in Figures 13, 14, 15 and 16.

Third Test: The third test consists of maximum power of 6800 W in the middle position with severe shading scenarios as demonstrated in Figures 17-20.

TABLE 3. Key Contributions of the Proposed Algorithm

Case	**Irradiance (W/m^2)**			**Power (W)**	
Test	PV1	PV2	PV3	Position	Max Power
01	374.8	332.4	417.3	Right	9100
02	417.3	232.4	374.8	Middle	6600
03	232.4	417.4	374.8	Middle	6800

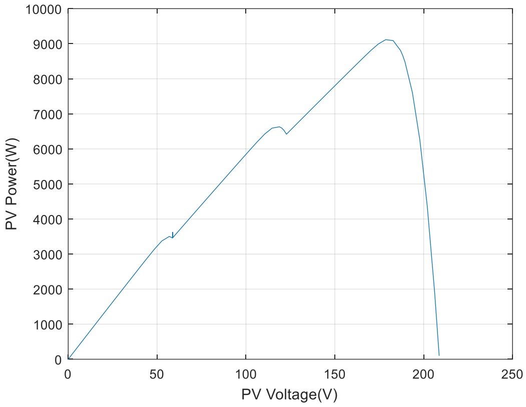

Figure 2. P-V Characteristics of the first Shading Scenario

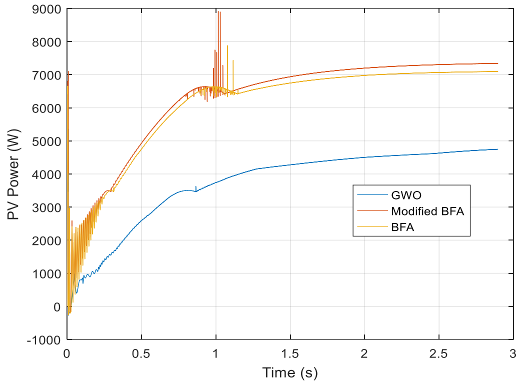

Figure 10. PV Power of During the First Shading Scenario

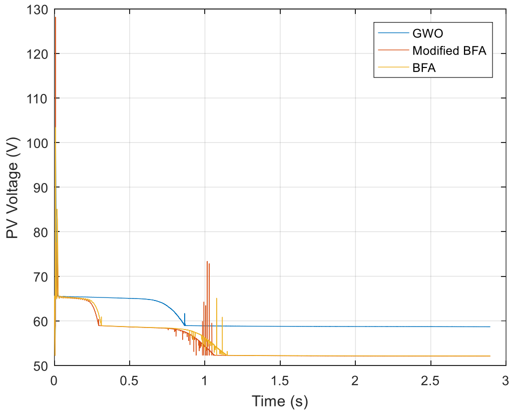

Figure 11. PV Voltage During the First Shading Scenario

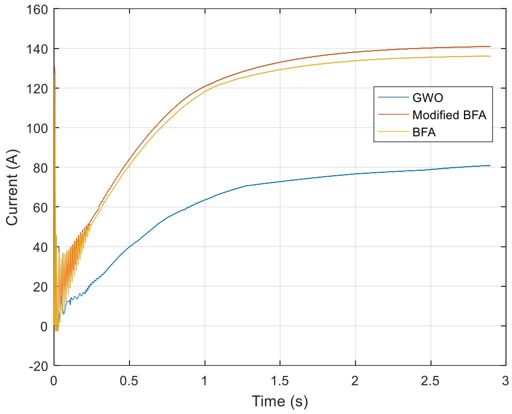

Figure 12. PV Current During the First Shading Scenario

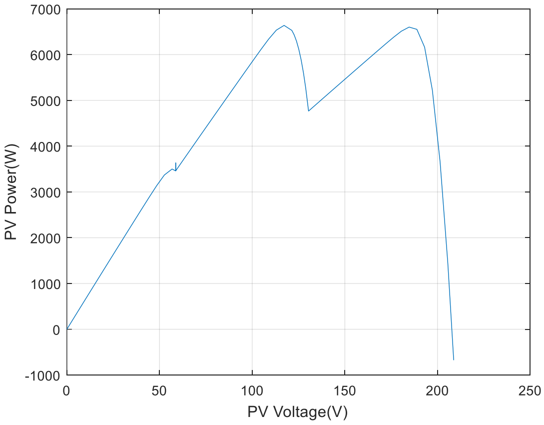

Figure 3. P-V Characteristics of the Second Shading Scenario

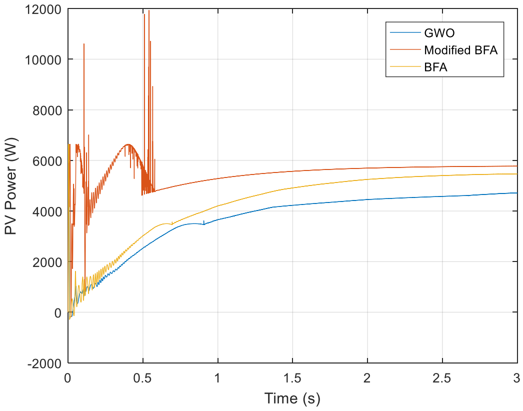

Figure 4. PV Power During the Second Shading Scenario

6. 4. Comparative Analysis

Comparisons with original bacterial foraging algorithm and commonly adapted grey wolf optimization MPPT algorithms highlighted the superior performance of the modified bacterial foraging (M-BFA) algorithm. Its ability to adaptively adjust mutation rates allowed it to explore the solution space effectively, escape local optima, and converge to the global MPP accurately 81.31% to 89.39% under varying shading conditions.

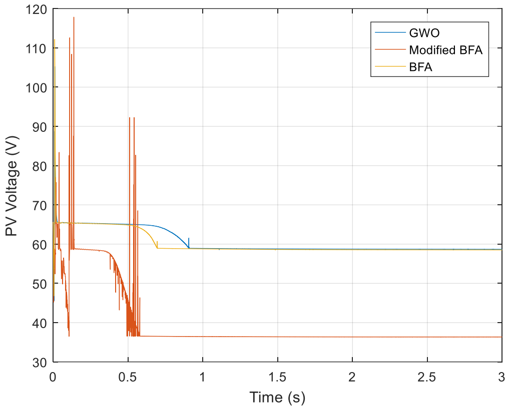

Figure 5. PV Voltage During the Second Shading Scenario

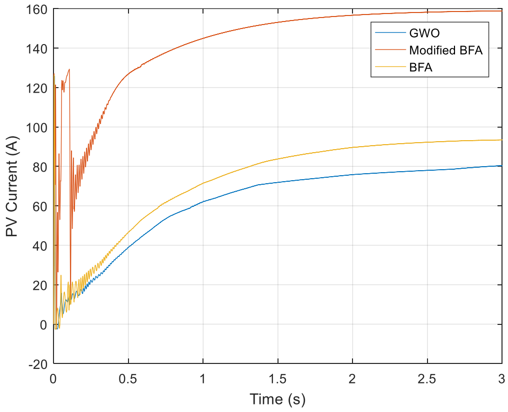

Figure 6. PV Current During the Second Shading Scenario

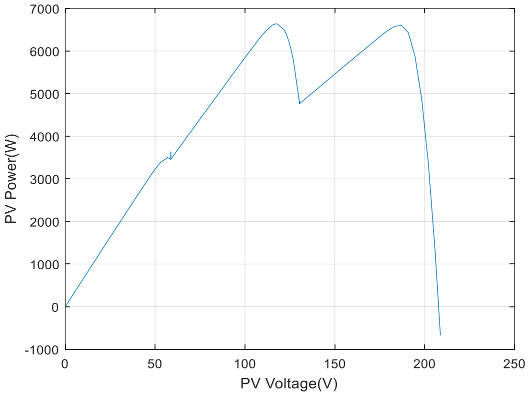

Figure 7. P-V Characteristics During the Third Shading Scenario

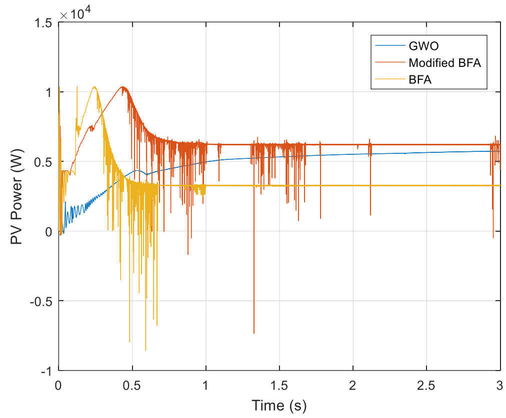

Figure 8. PV Power During the Third Shading Scenario

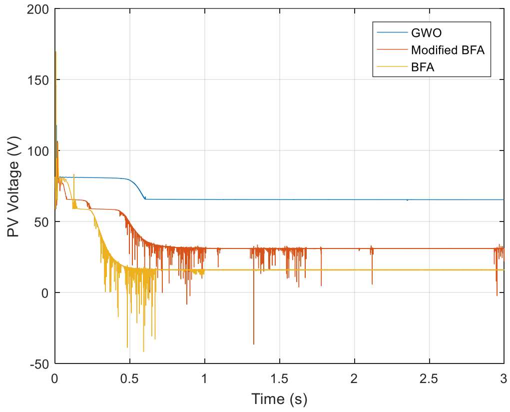

Figure 9 PV Voltage During the Third Shading Scenario

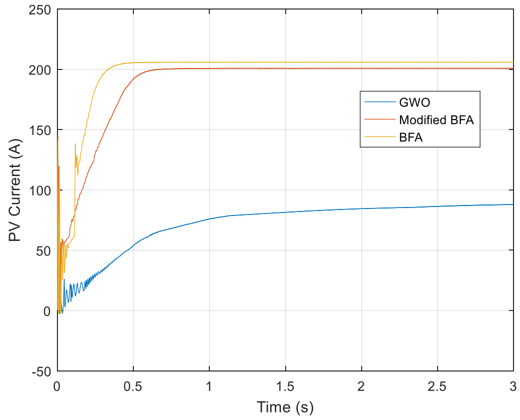

Figure 10. PV Current During the Third Shading Scenario

The simulation results provided strong evidence of the effectiveness and robustness of the proposed modified bacterial foraging algorithm with dynamic mutation for MPPT in photovoltaic systems under partial shading. The algorithm's adaptability to changing conditions and its capacity to navigate the complexities of multiple local MPPs make it a promising solution for enhancing the energy harvesting efficiency of PV systems, contributing to the advancement of renewable energy technologies.

As illustrated in Table 4:

TABLE 4. Result Comparison and Metrics

Test	Tracking Time (s)	Settling Time (s)	Power Tracking (W)	Power Accuracy (%)
Test 1	-	-	9100	100
M-BFA	0.9	1.5	7400	81.31
BFA	1	1.6	7050	77.47
GWO	1.25	2	4850	53.29
Test 2	-	-	6600	100
M-BFA	0.4	1.25	5900	89.39
BFA	0.6	1.4	5500	83.33
GWO	0.7	1.7	4900	74.24
Test 3	-	-	6800	100
M-BFA	0.4	0.75	6000	88.23
BFA	0.25	0.4	5800	85.29
GWO	0.5	1.2	4800	70.58

7. CONCLUSION

In the pursuit of harnessing renewable energy, optimizing photovoltaic (PV) systems has become essential. This study aimed to improve Maximum Power Point Tracking (MPPT) algorithms, particularly in partial shading scenarios, leading to the development of the Modified Bacterial Foraging Algorithm with Dynamic Mutation (M-BFA).

The M-BFA algorithm's core feature is its adaptability, similar to how bacteria adapt to their environment. This algorithm adjusts its mutation rate to balance exploration and exploitation. This mechanism combines traditional bacterial foraging principles with dynamic mutation, enabling the algorithm to navigate partial shading scenarios effectively.

To validate the M-BFA algorithm's capabilities, we conducted meticulous MATLAB Simulink simulations using a three-panel PV system facing various shading scenarios. Regardless of non-uniform illumination and multiple local maximum power points, the M-BFA algorithm consistently delivered precise and efficient maximum power point tracking delivering an accuracy of 89.39 % under challenging conditions and partial shading scenarios of Ain El Ibel Djelfa.

This study has broader implications beyond PV systems, as it represents a significant advancement in optimization techniques. M-BFA, combining biologyinspired exploration and dynamic mutation, represents a transformative development in Maximum Power Point Tracking. As renewable energy continues to play a crucial role in our future, this innovation demonstrates the potential for synergy between natural principles and human innovation, with applications extending beyond solar energy.

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Persian Abstract

چکیده

این مقاله تحقیقاتی رویکردی نوآورانه را برای ردیابی نقطه حداکثر توان (MPPT) در سیستم‌های فتوولتائیک ارائه می‌دهد، که با استفاده از یک الگوریتم جستجوی باکتریایی اصلاح شده با نرخ‌های جهش پویا انجام می‌شود. این روش به خصوص برای مقابله با چالش‌های ناشی از شرایط سایه‌زنی جزئی طراحی شده است و اطمینان از ردیابی کارآمد و سریع MPP در حالی که از گرفتار شدن در اوج‌های محلی جلوگیری می‌کند. برای ارزیابی عملکرد این تکنیک نوآورانه، تحلیل مقایسه‌ای در برابر الگوریتم جستجوی باکتریایی اصلی و الگوریتم بهینه‌سازی گرگ خاکستری انجام می‌شود، که هر دو به طور معمول در کاربردهای MPPT استفاده می‌شوند. الگوریتم اصلاح شده استراتژی منحصر به فردی را در بر می‌گیرد که نرخ‌های جهش را بر اساس رفتار همگرایی الگوریتم به صورت پویا تنظیم می‌کند و دقت ردیابی را از ۸۱/۳۱٪ به ۸۹/۳۹٪ افزایش می‌دهد. برای اعتبارسنجی اثربخشی تکنیک پیشنهادی، شبیه‌سازی‌های گسترده‌ای با استفاده از MATLAB Simulink انجام می‌شود و در نظر می‌گیرد شرایط سایه‌زنی جزئی مختلفی که به طور معمول در کاربردهای فتوولتائیک عملی مواجه می‌شوند. ارزشمند است بدانید که داده‌های سناریوی سایه‌زنی از وب‌سایت پیش‌بینی انرژی جهانی ناسا استخراج شده‌اند، به خصوص از رکوردهای تابش شهر عین الابل دجلفا. نتایج شبیه‌سازی بدون تردید برتری تکنیک MPPT جستجوی باکتریایی اصلاح شده را نسبت به هر دو الگوریتم از نظر کارایی ردیابی (۰/٤ ثانیه تا ۰/۹ ثانیه) و استحکام در شرایط سایه‌زنی جزئی نشان می‌دهد. یافته‌های این تحقیق بینش‌های ارزشمندی را در مورد مزایای بالقوه استفاده از رویکرد جستجوی باکتریایی اصلاح شده برای کاربردهای MPPT ارائه می‌دهند. این تکنیک‌های نوآورانه با توانایی افزایش قابل توجه عملکرد آن‌ها در سناریوهای واقعی شامل سایه‌زنی جزئی، آن را به یک گزینه امیدوار کننده برای بهینه‌سازی کارایی و خروجی توان سیستم‌های فتوولتائیک تبدیل می‌کند.