

# Parrot Optimization Algorithm for MPPT of PVS with DC Forward Device under Partial Shading Conditions

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## Abstract

Electricity is essential in various settings for multiple purposes to facilitate a wide range of activities. The use of solar energy for electricity generation offers a practical answer to a variety of challenges. Solar panels are frequently employed to convert sunlight into electrical energy. Incorporating a maximum power point tracking circuit (MPPTC) into the photovoltaic system (PVS) is crucial for enhancing its efficiency and ensuring optimal utilization. The study selects a DC to DC forward converter to serve as the MPPTC. Numerous conventional algorithms, including incremental conductance and perturb & observe (P&O), can be effectively employed for MPPTC under stable solar irradiance conditions. Modules in PVS that are interconnected to create a power generation system may encounter fluctuations in irradiance due to various factors, including trees, shading, dust, birds, clouds, and other environmental influences. This event causes the system to undergo a Partial Shading Condition (PSC). Conventional algorithms are not capable of identifying the ideal location for optimizing energy harvesting under PSC condition. It is essential to adopt an optimization approach to enhance the efficiency of the PVS while operating under PSC conditions. The document presents a novel optimization technique referred to as the "Parrot Optimization Algorithm (POA)" aimed at enhancing energy harvesting during PSC for MPPTC. This document additionally includes a comparative analysis of the POA, Modified Invasive Weed Optimization (MIWO), Modified Grey Wolf Optimization (MGWO), and Whale Optimization Algorithm (WOA). The Hardware-in-the-Loop (HIL) system is established using OPAL-RT units to obtain a range of data for analysis across different operational scenarios.

**Keywords:** Photovoltaic, Parrot Optimization Algorithm, MPPT, HIL, Partial Shading Conditions.

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## I. INTRODUCTION

Solar energy stands as the leading renewable energy source (RES) on the planet, available for use in nearly every location [1]. Solar energy presents a promising solution to numerous challenges [2], such as climate change and areas lacking access to an electrical grid. PV systems are commonly employed to produce the required electricity during sunny weather conditions. A significant number of PV cells must be connected in both parallel and series configurations to produce the required power at the

designated voltage level. Consequently, the likelihood of shading interference on PV cells from trees, clouds, birds, dust, and other factors is expected to increase [3-4]. The PSC on the PVS generally illustrates this phenomenon, complicating the identification of the maximum power location due to the existence of several points.

The MPPTC plays a vital role in improving the efficiency of a PVS across different operational points. An appropriate algorithm, in conjunction with a control strategy should be required to effectively manage the operation of

the MPPTC. A conventional P&O approach is generally employed to obtain MPPTC operation under stable solar radiation conditions. There will be a singular peak power point observable on the power versus voltage curve when subjected to stable solar irradiance. Regrettably, multiple maximum power points (MPPs) may arise during the process of PSC; however, only one will be identified as the Global Maximum Power Point (GMPP), while the remaining points will be classified as Local Maximum Power Points (LMPPs). Consequently, traditional P&O methods do not ensure the accurate identification of the GMPP. It is therefore crucial to adopt an optimization strategy to integrate the P&O technique, thereby facilitating the detection of the GMPP among various LMPPs. POA possesses the capability to precisely identify target objectives more efficiently than numerous other entities. This paper employs POA to efficiently identify GMPP among a collection of LMPPs. A forward DC converter is frequently selected as the optimal choice for MPPTC because of its various benefits. The adoption of 3DOF-PID controllers has facilitated a novel control strategy for the forward DC to DC converter.

The subsequent sections delineate the remaining research findings:

- Section-II: The structure of the proposed method has been streamlined to enhance clarity.
- Section-III: This section has been carefully designed to offer detailed insights into the POA+P&O methodology for identifying GMPP within PSCs.
- Section-IV: This section has been carefully developed to present the complete specifics of the suggested control mechanism for the FC.
- Section-V: Numerous results are encapsulated within this category through the application of HIL.
- Section-VI: Conclusions have been established for this specific section.

## II. OVERVIEW OF SYSTEM

Various PVMs should be arranged in both series and parallel configurations to attain the necessary PVS. In these situations, there is a significant probability that a shading effect may arise on specific modules due to multiple factors. A DC to DC converter is often required to adjust the voltage of the PVS to match the  $V_{mpp}$ , thereby optimizing its capacity for effective use. Numerous converters have been developed to manage the voltage of PVS. One example of a converter is the DC to DC FC, which is capable of efficiently regulating voltage over a broad range. This capability is essential for PVSs when they are functioning in conjunction with PSCs [25, 27]. A suitable control technique establishes a connection between the dc-bus and the PVS through a FC. The arrangement of the PVS layout with FC is shown in Figure 1. The FC possesses the ability to adjust the voltage to levels both below and above the input, enabling it to operate as a MPPTC under diverse conditions, including PSC and uniform irradiances. A technique has been established to recognize GMPP within PSCs among the numerous existing LMPPs. The approach

is additionally combined with the traditional P&O algorithm to enhance the efficiency of the system, even in stable irradiance conditions.

The proposed hybrid POA+P&O possesses the ability to produce  $V_{mpp}$ , which is then employed as an input signal for the control block of the FC. The proposed control method facilitates the swift and precise generation of a stable output voltage by the FC through the integration of 3DOF-PID controller.

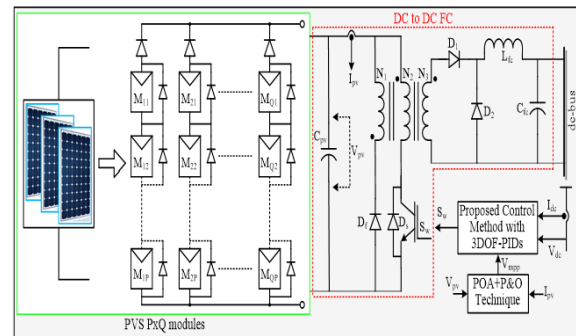


Fig. 1. POA Based FC Operated PVS

A significant number of scholars have recently published similar works. In [5-6], the authors have developed a control strategy utilizing genetic algorithms to MPPT control for PVSs functioning under PSC. In [6], researchers have also integrated artificial neural networks to create an improved MPPT algorithm. The researchers in references [7-10] have developed an algorithm based on PSO for PVS to function effectively under PSCs. The researchers in [11] employed a MGWO algorithm for PVSs to identify the GMPP while the PV cells were functioning. Researchers in references [12-13] proposed the MIWO approach, whereas those in references [14-15] implemented the WOA method to improve energy harvesting in PSCs. Researchers have implemented optimization-based MPP algorithms across various converters for a diverse array of applications [12-15]. The POA introduces an innovative bio-inspired metaheuristic strategy designed to tackle a diverse array of engineering problems. It has demonstrated its effectiveness as a superior algorithm for accurately identifying target values when compared to various other optimization methods [16], including GA, PSO, GWO, MIWO, and WOA. Consequently, this study has considered the POA method and combined it with the P&O approach to accurately identify the GMPP location in PVS. FC exhibits enhanced performance relative to various other DC to DC converters [17-20], while also displaying minimal fluctuations in output voltage, which is an essential attribute for power supply modules based on PVS. An essential prerequisite for the efficient functioning of FC is the establishment of a robust control method along with suitable controllers. The 3DOF-PID controller, in contrast to traditional PI controllers, possesses the ability to produce accurate and smooth output, even in the face of swift alterations within the system [21-23]. Consequently, the system's performance is likely to remain consistent and deliver enhanced responses under various operating conditions. This paper presents an innovative control strategy for FC that employs 3DOF-PID controllers. The

PVS integrates various parameters obtained from references [1, 11, 24, 26, 28] in the modeling process of the proposed model. The generated power may be consumed at a resistive load or a battery array for the purpose of charging, or it can alternatively be linked to an inverter to produce an AC output.

### III. POA+P&O METHODOLOGY

This paper discusses a PV system consisting of 12 PV modules, as depicted in Figure 2. Four PVMs are connected in a sequential manner to form a cluster, with three clusters interconnected in parallel. The ratings for an individual module are presented in Table-I. Various PSPs across distinct PVMs are applied, as demonstrated in Figure 2. Four potential PSCs are being evaluated, as shown in Table II, along with their corresponding P-V curves depicted in Figure 3. A review of Figure 3 indicates the necessity of employing an optimization strategy to ascertain  $P_{max}$ , given the inadequacies of the conventional P&O method. Consequently, a POA technique is developed and integrated with the P&O technique by employing the below process.

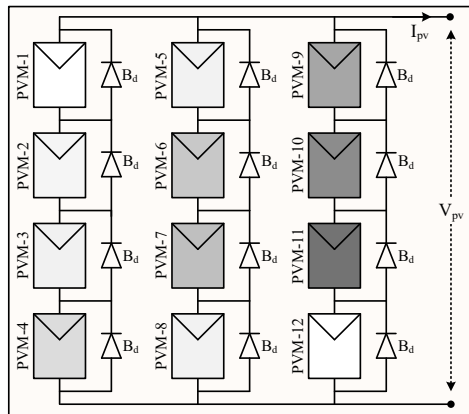


Fig. 2. Arrangements of PVS Under PSP of 12PVMs

TABLE I. RATINGS OF A PVM

| Parameters                                              | Values |
|---------------------------------------------------------|--------|
| $P_{max}$ corresponding to $1000\text{w/m}^2(\text{W})$ | 961.34 |
| Voltage at $P_{max}(\text{V})$                          | 113.09 |
| Current at $P_{max}(\text{A})$                          | 8.51   |
| Voltage at open circuited (V)                           | 138.01 |
| Short circuit current (A)                               | 9.03   |

TABLE II. FOUR PATTERNS OF PSCS

| S. No | PVMs      | PSP-1  | PSP-2  | PSP-3  | PSP-4  |
|-------|-----------|--------|--------|--------|--------|
| 1     | PVM-1     | 701    | 801    | 951    | 1000   |
| 2     | PVM-2     | 1000   | 801    | 551    | 401    |
| 3     | PVM-3     | 699    | 859    | 951    | 601    |
| 4     | PVM-4     | 901    | 440    | 852    | 803    |
| 5     | PVM-5     | 701    | 805    | 953    | 990    |
| 6     | PVM-6     | 900    | 599    | 440    | 405    |
| 7     | PVM-7     | 752    | 751    | 355    | 602    |
| 8     | PVM-8     | 845    | 551    | 957    | 795    |
| 9     | PVM-9     | 703    | 799    | 940    | 1000   |
| 10    | PVM-10    | 999    | 701    | 640    | 403    |
| 11    | PVM-11    | 847    | 651    | 960    | 602    |
| 12    | PVM-12    | 651    | 853    | 1000   | 801    |
| 13    | $P_{max}$ | 8436.0 | 6861.2 | 6718.1 | 5657.9 |
| 14    | $V_{mpp}$ | 469.4  | 473.3  | 345.7  | 357.4  |

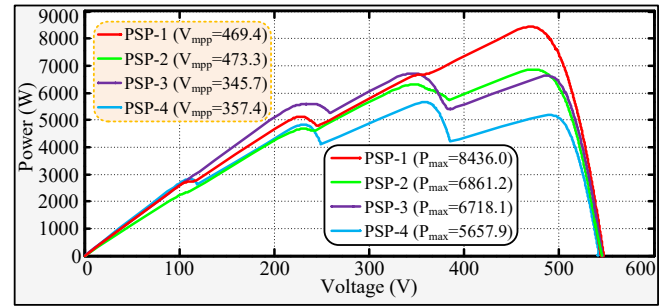


Fig. 3. Characteristics of PVS {as per Table-II}

The POA is a highly effective metaheuristic algorithm that is inspired by the foraging, resting, communication, and wariness of unfamiliar individuals, behaviors that are characteristic of domesticated *Pyrrhura Molinae* parrots. These behaviors are represented by four unique formulas designed to aid in the pursuit of optimal solutions. Unlike conventional metaheuristic algorithms that distinguish between separate phases of exploration and exploitation, each individual in the POA population randomly demonstrates one of these four behaviors in every iteration. This method offers a more accurate depiction of the behavioral variability seen in domesticated *Pyrrhura Molinae* parrots and greatly improves the diversity within the population. The POA successfully reduces the likelihood of becoming ensnared in local optima and preserves solution quality by departing from the traditional two-phase framework of exploration and exploitation. The stochastic nature of the POA sets it apart from conventional algorithms, rendering it especially effective in circumventing local optima and applicable to many fields.

Approach of POA:

#### A. Initialization of the Population

The initialization framework for the suggested POA method, taking into account a swarm size of  $N$ , a maximum number of iterations denoted as  $Max_{iter}$ , and the constraints of the search space defined by the lower bound  $lb$  and the upper bound  $ub$ , is represented as follows.

$$Y_i^0 = lb + r(0,1) \times (ub - lb) \quad (1)$$

In this context,  $(0,1)$  represents a random value within the interval  $[0, 1]$ , while ' $X_0$ ' signifies the initial position of the ' $i_{th}$ ' *Pyrrhura Molinae* during the preliminary stage.

#### B. Foraging behavior

In the context of foraging behavior in POA, individuals assess the general vicinity of food by either observing its placement or taking into account the position of the owner, subsequently flying towards the identified location. Consequently, the movement in relation to position adheres to the established equation.

$$Y_i^{t+1} = (Y_i^t - Y_{best}) \times Levy(dim) + r(0,1) \times \left(1 - \frac{t}{Max_{iter}}\right)^{\frac{2t}{max_{iter} \times Y_{mean}^t}} z \quad (2)$$

In Equation (2),  $Y_i^t$  represents the current position, while  $Y_i^{t+1}$  indicates the position following the next update.

The term  $Y_{mean}^t$  signifies the average location within the existing population, and ( $D$ ) refers to the Levy distribution, which is utilized to model the flight patterns of parrots. The variable  $Y_{best}$  denotes the optimal position identified from the beginning of the process up to the present moment, also reflecting the current position of the host. The symbol  $t$  indicates the current iteration count. The expression  $(Y_i^t - Y_{best}) \cdot (dim)$  represents movement relative to the best-known position, while  $r(0,1) \times \left(1 - \frac{t}{Max_{iter}}\right)^{\frac{2t}{max_{iter} \times Y_{mean}^t}}$  illustrates the observation of the overall population's position to refine the search for food. The average position of the existing swarm, represented by  $Xt$ , is determined using the formula provided in Equ. (3).

$$Y_{mean}^t = \frac{1}{N} \times \sum_{K=1}^N v_K^t \quad (3)$$

The Levy distribution can be derived using the rule specified in Equation (4), with the parameter  $\gamma$  set to 1.5.

$$\begin{cases} Levy(dim) = \frac{\mu\sigma}{|g|^{\frac{1}{\gamma}}} \\ \mu \sim N(0, dim) \\ g \sim N(0, dim) \\ \sigma = \left( \frac{r(1+\gamma) \times \sin\left(\frac{\pi\gamma}{2}\right)}{r\left(\frac{1+\gamma}{2}\right) \times 2\gamma^{\frac{1+\gamma}{2}}} \times \gamma + 1 \right) \end{cases} \quad (4)$$

### C. Staying behavior

Pyrrhura Molinae is an exceptionally social species, characterized by its tendency to abruptly take flight to various areas of its owner's body, where it will then remain still for a designated duration. This phenomenon can be depicted as:

$$Y_i^{t+1} = (Y_i^t + Y_{best}) \times Levy(dim) + r(0,1) \times ones(1, dim) \quad (5)$$

Where,  $(1, dim)$  denotes the all-1 vector of dimension  $dim$ .  $Y_{best} \cdot (dim)$  denotes the flight to the host, and  $r(0,1) \times ones(1, dim)$  denotes the process of randomly stopping at a part of the host's body.

### D. Communicating behavior

Pyrrhura Molinae parrots are naturally social creatures known for their strong communication within their groups. This communicative behavior includes both flying to join

the flock and engaging in communication while remaining grounded. In the proposed model, it is assumed that both behaviors occur with equal likelihood, and the average position of the current population is utilized to represent the center of the flock. The representation of this process can be expressed as:

$$Y_i^{t+1} = \begin{cases} 0.2 \times r(0,1) \times \left(1 - \frac{t}{Max_{iter}}\right) \times (Y_i^t - Y_{mean}^t), P \leq 0.5 \\ 0.2 \times r(0,1) \times \exp\left(-\frac{t}{r(0,1) \times Max_{iter}}\right), P > 0.5 \end{cases} \quad (6)$$

where,  $0.2 \times r(0,1) \times \left(1 - \frac{t}{Max_{iter}}\right) \times (Y_i^t - Y_{mean}^t)$  denotes the process of an individual joining a parrot's group to communicate and  $0.2 \times r(0,1) \times \exp\left(-\frac{t}{r(0,1) \times Max_{iter}}\right)$  denotes the process of an individual flying away immediately after communicating. Both behaviors are feasible and, as such, are implemented using randomly generated  $P$  within the range of  $[0, 1]$ .

### E. Fear of strangers' behavior

Birds typically display an inherent apprehension towards unfamiliar individuals, and Pyrrhura Molinae parrots are no exception to this tendency. Their inclination to maintain distance from strangers while seeking refuge with their owners in pursuit of a safe environment, as elaborated below.

$$Y_i^{t+1} = Y_i^t + r(0,1) \times \cos\left(0.5\pi \times \frac{t}{Max_{iter}}\right) \times (Y_{best} - Y_i^t) - \cos(r(0,1) \times \pi) \times \left(\frac{t}{Max_{iter}}\right)^{\frac{2}{Max_{iter} \times (Y_i^t - Y_{best})}} \quad (7)$$

Where,  $r(0,1) \times \cos\left(0.5\pi \times \frac{t}{Max_{iter}}\right) \times (Y_{best} - Y_i^t)$  shows the process of reorientating to fly towards the owner and  $\cos(r(0,1) \times \pi) \times \left(\frac{t}{Max_{iter}}\right)^{\frac{2}{Max_{iter} \times (Y_i^t - Y_{best})}}$  shows the process of moving away from the strangers.

The  $Y_{best}$  is considered as  $V_{mpp}$  of PV system which is GMPP under PSC.

## IV. PROPOSED CONTROL METHODOLOGY

The  $V_{mpp}$  derived from POA and P&O within the framework of PSCs, which aligns with  $P_{max}$ , will act as the benchmark input signal for regulating the FC methodology. 3DOF PID controllers are utilized in the proposed control strategy of FC. The  $V_{mpp}$  is evaluated against the actual voltage at the DC-bus to produce the error signal, which is subsequently input into a 3DOF-PID controller to determine the current reference value for the DC-bus. The present

reference is once again evaluated against the actual  $I_{dc}$ , and the resulting error is fed into a Hysteresis controller to generate signals for the switch  $S_w$  of the FC. The control methodology is depicted in Figure 4. Figure 5 presents the essential block diagram of a 3DOF-PID controller.

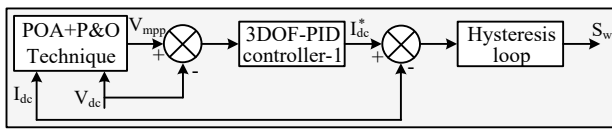


Fig. 4. Proposed POA based control strategy of FC.

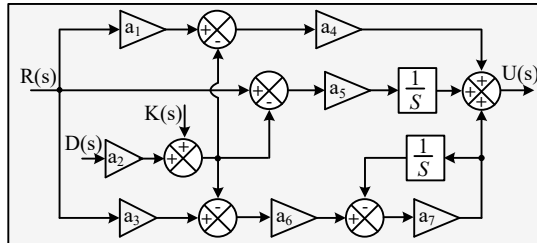


Fig. 5. Simple sketch of a 3DOF-PID controller

## V. HIL BASED RESULTS

The implementation of a HIL configuration utilizing two OPAL-RT modules results in varied outcomes, enabling the system to replicate real-time experiences effectively. To develop a HIL system, the suggested MATLAB model is segmented into two components: the plant and the control unit. The system consists of PVMs, FC, electrical loads, and sensors for detecting voltage and current. The control unit is combined with the proposed control strategy, which includes the MPPT algorithm. Data cards are generally linked between two OPAL-RT modules to enable the transfer of data. The control unit will obtain the digital signals from the plant unit through the use of analog to digital cards. The facility will also possess the ability to accept the analog pulse signal (to  $S_w$ ) from the control unit through the use of digital to analog patch cards. The examination presented in this section confirms and elucidates a range of findings obtained from a system. The fundamental block diagram of the HIL setup is illustrated in Figure 6.

The algorithm in question has undergone testing in accordance with the conditions specified below:

*Condition-A:* From  $t=0$  to  $t=1.0$  seconds, a uniform solar irradiance (USI) was observed. During this time frame, all PV modules were subjected to the same level of irradiance (i.e.,  $1000\text{W/m}^2$ ).

*Condition-B:* The PSP-1 is employed under the time period from  $t=1$  to 1.5 seconds, as shown in Table-II.

*Condition-C:* The PSP-2 is employed under the time period from  $t=1.5$  to 2 seconds, as shown in Table-II.

*Condition-D:* The PSP-3 is employed under the time period from  $t=2$  to 2.5 seconds, as shown in Table-II.

*Condition-E:* The PSP-1 is employed under the time period from  $t=2.5$  to  $3.25$  seconds, as shown in Table-II.

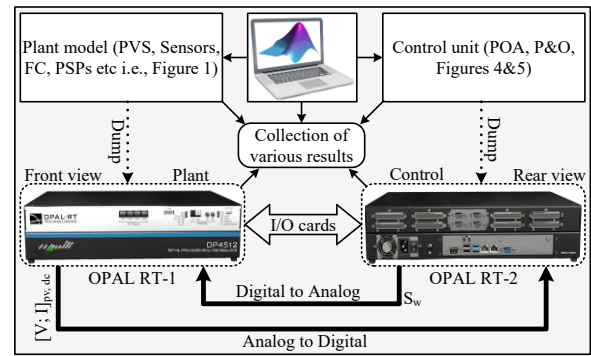


Fig. 6. Setup of a HIL Using OPAL-RT Devices

The PSP-1 is employed under the time period from  $t=2.5$  to  $3.25$  seconds, as shown in Table-II. The control method developed in Figure 4 produced suitable signals for the FC by employing 3DOF-PID controller. Consequently, the FC regulates the voltage to the designated level, as illustrated in Figure 7. The  $V_{pv}$  is monitoring its  $V_{mpp}$ , as depicted in Figure 7, thereby validating the effective functioning of the proposed MPPT mechanism. Figure 8 depicts the energy produced by PVS.

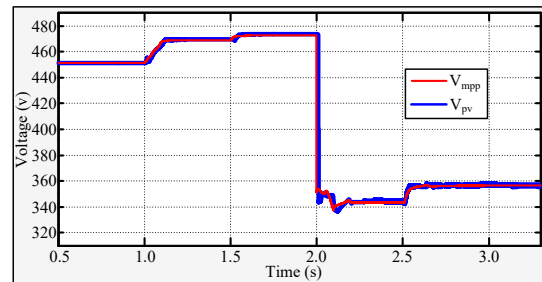


Fig.7. Responses of Voltages

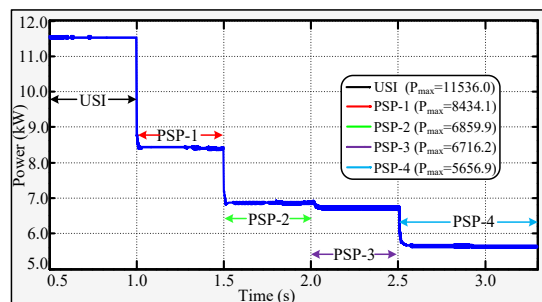


Fig. 8. Powers Under Various PSPs

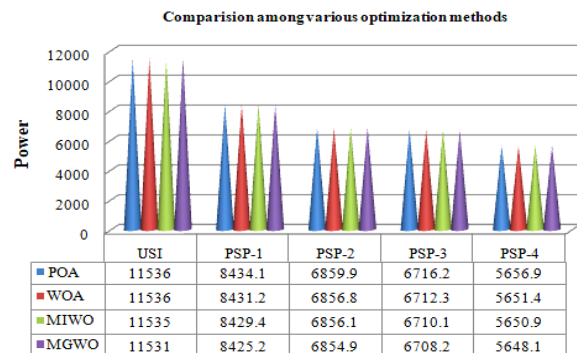


Fig. 9. Response With Various Methods Over Proposed Method

The efficacy of the proposed methodology is evaluated in relation to MIWO [12], MGWO [11] and WOA [15]. A comparative analysis and illustration of their respective capabilities are presented in Figure 10. 1. A review of Figure 9 clearly demonstrates that the proposed method, namely POA, operates effectively even under the most challenging conditions of PSPs, particularly during the transition from PSP-2 to PSP-3. The POA achieves this by employing FC, which efficiently regulates the direct current voltage and reduces fluctuations. Reducing fluctuations in the DC voltage can improve power extraction efficiency by lessening power oscillations. Furthermore, this may reduce the quantity of heat produced at the PVS terminals. The suggested approach is highly significant for optimizing energy extraction from PVSs during PSCs. The proposed method convergence is also depicted in Figure 10 along with other methodologies. From Figure 10, it is observed that, the proposed method is having more efficient as other methods.

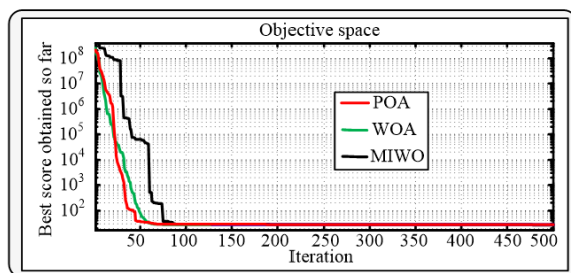


Fig. 10. Convergence of POA Over WOA, MIWO

## VI. CONCLUSION

The document presents an innovative optimization method referred to as 'POA' aimed at identifying the most effective power placement across various PSPs. An FC is recognized as an MPPT circuit capable of regulating the DC voltage while minimizing ripples. Consequently, an increased quantity of energy can be achieved with lower heat levels at the terminals of the PVU. The developed strategy has been formulated utilizing 3DOF-PID controllers, which facilitate the generation of smoother reference values in comparison to alternative controllers. The effectiveness of the proposed methodology in generating power is subsequently assessed in comparison to MGWO, MIWO, and WOA. The results are presented using HIL simulation, and satisfactory outcomes are evidenced through a comprehensive analysis.

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