A novel optimization of the particle swarm based maximum power point tracking for photovoltaic systems under partially shaded conditions

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ABSTRACT
When the irradiance distribution over the photovoltaic panels is uniform, the pursuit of the maximum power point is not reached, which has allowed several researchers to use traditional MPPT techniques to solve this problem. Among these techniques a PSO algorithm is used to have the maximum global power point (GMPPT) under partial shading. On the other hand, this one is not reliable vis-à-vis the pursuit of the MPPT. Therefore, in this paper we have treated another technique based on a new modified PSO algorithm so that the power can reach its maximum point. The PSO algorithm is based on the heuristic method which guarantees not only the obtaining of MPPT but also the simplicity of control and less expensive of the system. The results are obtained using MATLAB show that the proposed modified PSO algorithm performs better than conventional PSO and is robust to different partial shading models.

Keywords:
Modified P&O algorithm
Modified PSO algorithm
MPPT control
Partial shading
PV array
PV module

1. INTRODUCTION
Photovoltaic (PV) is alternative source of clean and renewable energy of high importance to environmental friendliness and low maintenance cost [1], [2]. The output characteristics of the photovoltaic generators are not linear because they always vary according to the solar irradiance and the temperature of the module. However, it is reported in the literature for a system of uniformly shaded photovoltaic panels. That the performance of perturb and observe (P&O) algorithm in the detecting the MPP is very efficient [3], [4]. But in the case of partial shading, this algorithm will not achieve its goal. Since the P-V curve has multiple peaks; evolutionary optimization technique such as Particle Swarm Optimization (PSO) could be used to detect MPP techniques where conventional algorithms fail to converge under partial shading [5], [6]. In this paper we will propose an improved maximum power point tracking (MPPT) method for the PV system using a modified PSO algorithm. Particle swarm optimization (MPSO) algorithm is adopted in detecting the global MPP of a partially shaded PV array [7], [8]. The results obtained from this algorithm will be compared to the Perturb and Observe for the single peak characteristics of the P-V. A similar comparison is made for the multi-peak characteristic of P-V between MPSO and MP&O of a partially shaded PV array. The rest of the paper is organized as follows. In Section 2, the circuit model of PV cell and characteristic of PV array are presented. The studied PV array system under partially shaded is illustrated in Section 3. MPP
detection using the MP&O algorithm and MPSO are presented in Sections 4. Results are presented and discussed in Section 5. At the end, conclusion is given in Section 6.

2. MODELING OF A PV ARRAY WITH UNIFORM IRRADIATION

The photovoltaic panel consists of several solar cells. Energy production can be increased by connecting the PV in series or in parallel. The circuit of a photovoltaic cell is shown in Figure 1. The output PV current depends on the temperature and solar irradiation. The equations given below are used to describe the modeling of the single PV module [9], [10]. The current (Iph) is given by:

\[ I_{PV} = I_{ph} - I_0 \left( e^{\frac{V_{PV} + R_s I_{PV}}{N_s R_t}} - 1 \right) - \frac{V_{PV} + R_s I_{PV}}{R_p} \] (1)

\[ I_{ph} = I_{cc} = I_{cc, stc} \left( \frac{G}{G_{stc}} \left[ 1 + K_I \left( T - T_{stc} \right) \right] \right) \] (2)

With

\[ V_t = \frac{kT}{q} \] (3)

\[ I_{ph} = I_{Scr} \frac{G}{G_{r}} \] (4)

Then (1) becomes:

\[ I_{PV} = I_{sc} - I_0 \left( e^{\frac{V_{PV} + N_s R_s I_{PV}}{N_s R_t}} - 1 \right) - \frac{V_{PV} + N_s R_s I_{PV}}{N_s R_p} \] (5)

![Figure 1. Equivalent circuit of a PV panel](image)

The solution of (5) is obtained, for a grid of values of the current I, by using the bisection method in order to solve the f(VPV)=0 in the interval [0 Voc] where:

\[ f(V_{PV}) = I_{PV} - I_{sc} + I_0 \left( e^{\frac{V_{PV} + N_s R_s I_{PV}}{N_s R_t}} - 1 \right) + \frac{V_{PV} + N_s R_s I_{PV}}{N_s R_p} \] (7)

3. MODELING OF A PV ARRAY UNDER PARTIAL SHADING

For verify the capability of an algorithm used to detect the global MPP of a partially shaded PV array, it is important to have a physical PV array assembly or its theoretical model [11], [12]. The challenge in such
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Table 2. Simulation results for the different power points with configurations C₁, C₂, C₃

| Configuration | G W/m² | Pₚ₁(W) | Pₚ₂(W) | Pₚ₃(W) | G W/m² | Pₚ₁(W) | Pₚ₂(W) | Pₚ₃(W) |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Configuration C₁ | 1000   | ------ | ------ | 7998   | 1000   | ------ | ------ | 7998   |
| 900           | ------ | ------ | ------ | 7572   | 900    | ------ | ------ | 7325   |
| 800           | 1710   | 4725   | 7043   | 800    | 1629   | 2970   | 6569   |
| 700           | 1710   | 4530   | 6485   | 700    | 1596   | 2759   | 5768   |
| 600           | 1710   | 4307   | 5890   | 600    | 1560   | 2542   | 4951   |
| 500           | 1710   | 4086   | 5321   | 500    | 1531   | 2327   | 4110   |
| 400           | 1710   | 3865   | 4700   | 400    | 1490   | 2209   | 3263   |
| 300           | 1710   | 3645   | 4102   | 300    | 1450   | 1891   | 2388   |
| 200           | 1710   | 3426   | 3498   | 200    | 1423   | 1691   | 1530   |
| 100           | 1710   | 3208   | 2891   | 100    | 1375   | 1477   | 685    |

Figure 4. (V-I, V-P) characteristics of the PV system under PSC, (a) V-I; (b) V-P

Figure 5. P-V curves of the PV array for different shaded modules irradiation level

4. BASICS OF MODIFIED P&O, MODIFIED PSO

In this article we have compared the modified PSO method and the modified P&O method. The performance of PSO modified is evaluated in comparison with P&O modified [15], [16]. Brief overviews of these methods are presented in this paper to facilitate the following discussion.

4.1. Modified P&O

The solution that we propose to overcome this problem is to scan by varying the value of the duty cycle D while saving the maximum value of the passing power. This will detect the true MPP [17], [18]. The modified P & O algorithm program considers the steps:

a. Use a logical variable shad which takes the value 1 in case of detection of shading (sudden decrease of the power).

b. If there is no shading (shad = 0), the MPPT works with the classic P & O program.
c. If there is shading (shad = 1): A cyclic report program close to the global MPP is started. It assigns to the
duty cycle D values ranging from 0 to 0.9 with a step of 0.1, then saves the value that gives the greatest
power in the variable D_PM. This therefore allows us to be injected to the operating point in the vicinity
of the overall MPP.

d. When D_PM is found the variable shad is reset to 0 and D_PM is assigned to D in order to restart
the conventional P & O algorithm with an initial operating point in the vicinity of the global MPP.

4.2. MPP detection using PSO

PSO was first introduced in [19], [20], which is an effective method for multimodal function global
optimization and swarm intelligence optimization search guide produced by cooperation and competition
among particles in swarm. we firstly give the solution vector definition with NP particle duty ratio
is shown in Figure 6. The position of the individual particle is calculated with [21], [22].

\[
\begin{align*}
    v_i^{k+1} &= w_i v_i^k + c_1 r_1 (p_{bi}^k - s_i^k) + c_2 r_2 (g_b^k - s_i^k) \\
    s^{k+1} &= s_i^k + v_i^{k+1}
\end{align*}
\]

Where; \( v_i^k \): particle i velocity at iteration k, \( i \): number of particle, \( w_\): weighting function, \( C_1 \): cognitive
coefficient, \( C_2 \): cognitive coefficient, \( r_1, r_2 \): random parameter,[0,1], \( s_i^k \): current position vector, \( p_{bi} \): best position
found by particle \( i \), \( g_b \): global best positions by particle in the group

A linearly decreasing inertia weight from maximum value to minimum value, as reflected in (10), is
used to update the inertia weight as (10) \( w_H, w_L \).

\[
w(k) = w_H - \frac{k}{k_H} (w_H - w_L)
\]

Where \( k_H \) is the maximum number of iterations and \( k \) is the iteration number. The fitness function of PSO
algorithm for tracking GMPP can be expressed as (11):

\[
\text{fitness}(V_p, I_p) = V_p I_{sc} - V_p I_R \left( e^{-\frac{g(V_p+I_R R_s)}{A K T}} - 1 \right)
\]

To start the optimization process, a vector of duty cycles are initialized and the algorithm transmits
the duty cycles to the power converter. These duty cycles (represented by \( S \) in (11) serve as the initial particles
in the first iteration. All particles are heading towards their local best position \( p_{bi} \)[23]. Among these particles,
one of them is the global best \( p_{bi} \). It gives the best fitness value. After calculating the velocity, which serves
as a perturbation to the voltage, a new position of the voltage is found. Through successive iteration all
particles move towards global best position. As the particles approach the MPP, they get closer to the
\( g_b \) position. Correspondingly, the \( p_{bi} \) factor and \( g_b \) factor in velocity term moves towards zero. Eventually a
zero velocity is achieved and the voltage position remains almost unchanged. Under this condition, the PV
system reaches at MPP [24], [25].
5. RESULTS AND DISCUSSION

To compare the performance of conventional P&O and PSO during partial shading, we introduced PV modules (A, B, C and D) in series. Consequently, there exists only one MPP at 8KW, as shown by Curve 1 of Figure 7. After a period of one second, the modules A, B, C and D are irradiated (partial shading) with 1000 W/m², 800 W/m² and 300W/m² respectively, therefore, several 4.077KW peaks, 5.243KW and 1.744KW are generated which are shown by curve 2 in Figure 7.

Figure 8 shows that the P&O algorithm is quickly trapped by the 1.744KW peak which is indicated by the arrows produced by moving the operating point from curve 1 to curve 2. Always in the PV system, the offset between the global and local peak is 40 W, or about 14% of the peak power, as well a loss of power considered to be very large are illustrated in Figure 8. In the Figures 9 (a)-(d), we notice that the PSO algorithm under partial shading begins to detect the overall 4077KW point of MPP and the tracking, as indicated by the movements of the particles (using the direction of the arrow) after several iterations. To evaluate the proficiency and robustness of the suggested GMPP tracking method, MATLAB/Simulink is hired. Modeling of solar Module, PSO algorithm and DC-DC boost converter is designed in MATLAB environment. The code for dynamic PSO algorithm is developed in S-function builder. Figures10(a)-(d) illustrates the output power curves of a PV system using the MPSO and MP&O methods at varying radiations.

Figure 7. P–V curve for MPP tracking under partially partially shaded with conventional PSO

Figure 8. P–V curve for MPP tracking undershaded with conventional P&O

Figure 9. The PV module (a) the PV module output power (w), (b) the PV module duty cycle, (c) the PV module voltage (v), (d) the PV module current (a), under partial shading by modified (P&O and PSO)
6. CONCLUSION

In this paper, a study of the partial shading effect on the modified particle swarm optimization (PSO) MPPT controlled PV array solar system has been presented and the modified perturb and observe (P&O) techniques have been calculated for a 100 module PV array using a moderate then a severe shading configuration. The results obtained indicate, this PSO MPPT algorithm should be modified to take into account the partial shading effect for a low insolation level. The proposed MPPT method tracks the global MPP for the two shading configurations and under the four given shading levels. The principal objective of this paper is to present the MPPT method based modified PSO algorithm for extraction of GMPP for PV system. The suggested modified PSO technique could be performed appropriately during PSC, pointed the GMPP for achieving a better compare with modified P&O method during PSC. The simulation results operation for PV system. The suggested algorithm also made to depict that modified PSO is more effectual, has high convergence rate and less ripple, tracking efficiency of modified PSO is remarkable as matched to conventional modified P&O algorithm. So, modified PSO algorithm is matchless in its performance. In this paper MPSO based MPPT and simulation results under normal and partially shaded conditions are presented. The PV curves show multiple peaks under partially shaded conditions. Results show that MPSO algorithm with high accuracy can track the real peak power point under different irradiation and temperature as well as partially shaded conditions. In addition, MPSO has a better time response and also their convergence speed is higher than other algorithms. It overcomes the weaknesses of conventional direct control method particularly in partial shading conditions. results have shown that the proposed method outperforms the conventional method in terms of tracking performance under ten different irradiance conditions, including various patterns for partial shading.

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