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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.

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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:

$$I_{PV} = I_{Ph} - I_0\left(e^{\frac{V_{PV}+R_S I_{PV}}{N_S V_t}} - 1\right) - \frac{V_{PV}+R_S I_{PV}}{R_p} \quad (1)$$

$$I_{Ph} = I_{cc} = I_{cc\_stc}\frac{G}{G_{stc}}[1 + K_I(T - T_{stc})] \quad (2)$$

With

$$V_t = \frac{kT}{q} \quad (3)$$

$$I_{Ph} = I_{Scr}\frac{G}{G_r} \quad (4)$$

Then (1) becomes:

$$I_{PV} = I_{sc} - I_0\left(e^{\frac{V_{PV}+N_S R_S I_{PV}}{nV_t N_S}} - 1\right) - \frac{V_{PV}+N_S R_S I_{PV}}{N_S R_p} \quad (5)$$

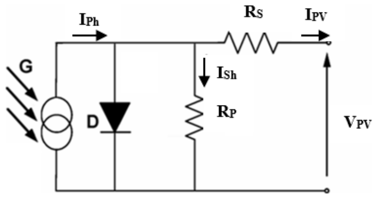


Figure 1. Equivalent circuit of a PV panel

The panel in parallel and panel in series form a photovoltaic field. The generator voltage V1, the current I1 and the power P1 under uniform irradiation can be obtained from the voltage Vpv and the current Ipv of the PV module as follows:

$$\begin{cases} V_1 = N_{ss} \times V_{PV} \\ I_1 = N_{pp} \times I_{PV} \\ P_1 = V_{PV} \times I_1 = N_{ss} \times N_{pp} \times V_{PV} \times I_{PV} \end{cases} \quad (6)$$

Where: Nss and Npp are respectively the series and parallel number of PV modules in the array.
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:

$$f(V_{PV}) = I_{PV} - I_{sc} + I_0\left(e^{\frac{V_{PV}+N_S R_S I_{PV}}{nV_t N_S}} - 1\right) + \frac{V_{PV}+N_S R_S I_{PV}}{N_S R_p} \quad (7)$$

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 studies is the need for simulating an enormous Ns and Np connected PV modules simultaneously, because each PV unit might be subjected to a different irradiance level. Of which a high computational time and therefore oftentimes becomes challenging to simulate and study these systems. A method to model the power peaks of partially shaded PV systems using empirical equations is available in the literature [13], [14]. It estimates the current IPV, voltage VPV and power PPV of the possible peaks shaded partially PV systems. The system under study is composed of 10×10 PV modules operating under the shading scenario depicted in. Figure 2 shows the effect on the characteristics of the PV array under partially shading. When the shaded modules receive an irradiation level of G = 0.1 kW/m^2, the I-V and P-V characteristics are obtained. We can see from this figure that the P-V curve is formed of three different hills with three maximum power points, two local maximums and one global maximum. The standard characteristics of the PVs used are shown in Table 1. The simulation is performed using the one diode model for the solar panel. The simulation is carried out using the one-diode model for the solar panel. Initially each module receives a uniform irradiance of 1000W/m^2. Four configurations of C_1, C_2, C_3 and C_4 with, uniform irradiation, light shading, medium shading, hard shading, is shown in Figure 3, were used in all simulations of the different shaded modules with an irradiation of 1000W/m^{2}resulting in three peaks represented in the maximum power points Pm_1, Pm_2, Pm_3 as indicated in the Table 2.

Table 1. PV module manufacturersuntech STP080 12/B6monocrystalline

Short-circuit current	I_{sc}	4.95V
Open circuit voltage	V_{oc}	21.9V
Maximum power current	I_m	4.57A
Maximumpower voltage	V_m	17.5V
Maximum power	P_m	80W
Short-circuit current Temperature coefficient	K_I	0.020 %/K
Open circuit voltage Temperature coefficient	K_V	-0.34 %/K

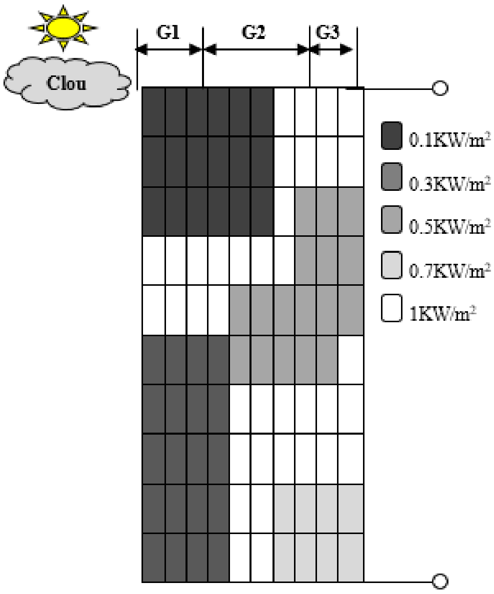
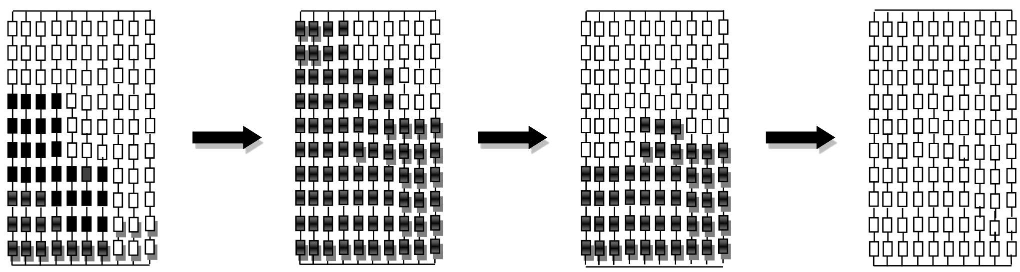


Figure 2. PSC caused by the clouds on PV system



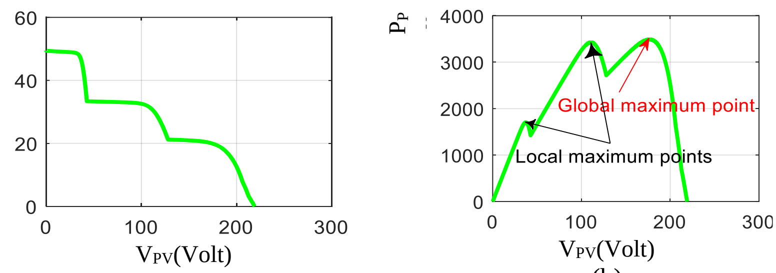
(a) (b) (c) (d)

Figure 3. Different configurations with, (a) C_1 (uniform irradiation), (b) C_2 (lightshading), (c) C_3 (medium shading), (d) C_4 (hard shading)

In addition, the variation in the irradiations of the shaded modules changes the position of the global MPP. But the latter remains at its maximum VAm, when G = 0.2 kW/m^2. Figure 4 show V-I, P-V curves of the PV array for different shaded modules with irradiation 0.1 kW/m^2, the increase of power is increasing with different irradiation of a partially shaded PV array is shown in Figure 5 with different shaded modules irradiation level.

Table 2. Simulation results for the different power points with configurations C_1, C_2, C_3

	G W/m^2	P_{1m}(W)	P_{2m}(W)	P_{3m}(W)		G W/m^2	P_{1m}(W)	P_{2m}(W)	P_{3m}(W)
Configuration C1	1000	------	------	7998	Configuration C2	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
Configuration C3	1000	------	------	7998	Configuration C4	1000	------	------	7997
	900	------	------	7502		900	------	------	7568
	800	3427	4498	6734		800	------	------	7042
	700	3427	4231	5980		700	------	------	4529
	600	3427	3964	5155		600	------	------	4307
	500	3427	3699	4298		500	------	------	4082
	400	3427	3435	3429		400	------	------	3865
	300	3427	3171	2536		300	------	------	3644
	200	3427	2909	1640		200	------	------	3424
	100	3427	2649	730		100	------	------	3197



(a) (b)

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

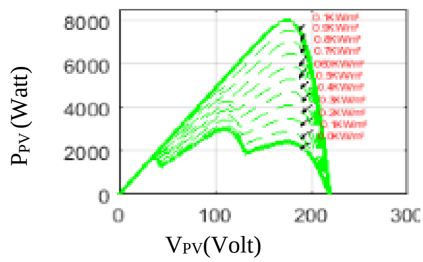


Figure 5. P-V curves of the PV array for different shaded modules irradiation level

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 proposeto overcome this problem is to scan by varyingthe 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 isan effective method for multimodal function global optimization and swarm intelligence optimizationsearchguide produced by cooperation and competition among particles in swarm. we firstly give the solution vector definition with NPparticle duty ratiois shown in Figure 6. The position of the individual particleis calculated with [21], [22].

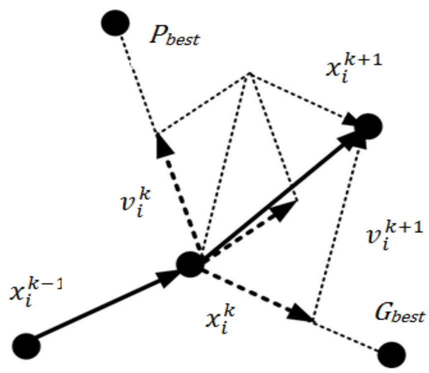


Figure 6. Movement of particles in PSO

$$v_i^{(k+1)} = w.v_i^k + C_1^k.r_1.\left(p_{bi}^k - s_i^k\right) + C_2^k.r_2.\left(g_b^k - s_i^k\right) \quad (8)$$

$$s^{(k+1)} = s_i^k + v_i^{(k+1)} \quad (9)$$

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.

$$w(k) = w_H - \frac{k}{k_H}(w_H - w_L) \quad (10)$$

Wherek_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):

$$fitness(V_P, I_P) = V_P I_{sc} - V_P I_R \left(e^{\frac{q(V_P + I_P R_S)}{A.K.T}} - 1\right) \quad (11)$$

To start the optimization process, a vector of duty cycles areinitialized and the algorithm transmits the duty cycles to the power converter. These duty cycles (representedby$S_i$in (11) serve as the initial particles in the first iteration. All particles are heading towards their local bestpositionp_{bi}[23]. Among these particles, one of them is the global best p_{bi}. It gives the best fitness value. Aftercalculating 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 theMPP, they get closer to the $g_b$position. Correspondingly, the p_{bi}factor and $g_b$factor in velocity termmoves towards zero. Eventually a zero velocity is achieved and the voltage position remains almostunchanged. 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/m^2 and 300W /m^2 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.

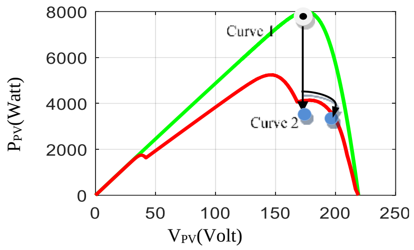


Figure 7. P–V curve for MPP tracking under partially partially shaded with conventional PSO

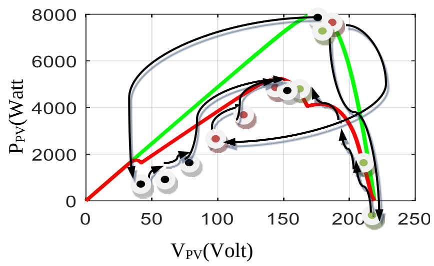


Figure 8. P–V curve for MPP tracking undershaded with conventional P&O

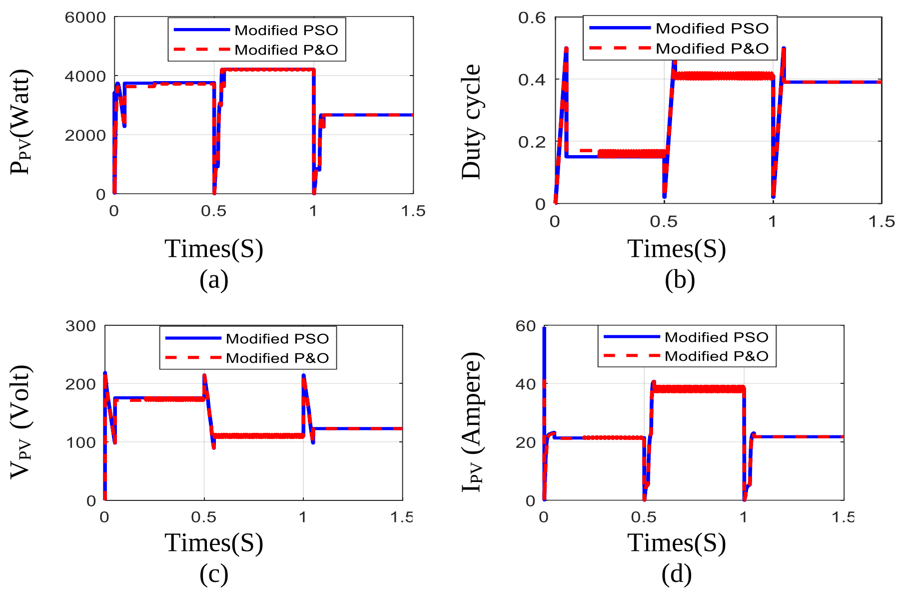


Figure 9. The PV module (a)the PV module output power (w), (b) the PV module duty cycle, (c) the PVmodule voltage (v), (d) the PV module current (a), under partial shading by modified (P&O and PSO)

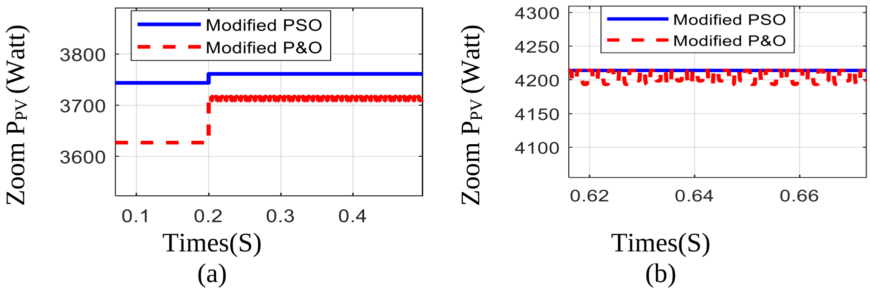


Figure 10. Zoom output power (W) under partial shading by modified, (a) P&O; (b) PSO

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). The power loss due to the inability of the PSO MPPT algorithm to track the maximum available power has 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 suggestedmodified PSO technique could be performed appropriately during PSC, pointed the GMPP for achieving a better compare with modified P&Omethod 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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