Analysis of Improved PSO and Perturb & Observe Global MPPT Algorithm for PV Array under Partial Shading Condition

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Abstract: The power-voltage (P-V) characteristic curve of photovoltaic (PV) system have nonlinear and multiple peaks characteristics under partial shading condition. This paper proposes a novel maximum power point tracking (MPPT) control method for PV system based on an improved particle swarm optimization (PSO) algorithm and variable step perturb and observe (P&O) method. Firstly, the grouping idea of shuffled frog leaping algorithm (SFLA) is introduced into the basic PSO algorithm, ensuring the differences among particles and the searching of global extremum. And then, the variable step P&O method is used to track the global maximum power point (GMPP) accurately with the change of environment. Finally, the superiority of the proposed method over the traditional PSO algorithm in terms of tracking speed and steady-state oscillations is highlighted by simulation and experimental results under partial shading condition.

Key Words: maximum power point tracking (MPPT), particle swarm optimization (PSO), shuffled frog leaping algorithm (SFLA), perturb and observe (P&O), photovoltaic (PV) systems, under partial shading condition

1 INTRODUCTION

As a sustainable and clean energy which is the most widely distributed in the world, solar energy has been generally concerned by government and human. However, in practical engineering applications, PV systems still have lots of problems needed to be solved urgently, and one of the key issues is to find a kind of rapid and effective MPPT algorithm, which has important significance for improving the efficiency of PV systems. Under partial shading condition, the output characteristic curves of PV arrays have highly non-linear and multi-peak characteristics. Some traditional MPPT algorithms (such as P&O method [1], incremental conductance (IC) method [2] and hill climbing (HC) [3]) can't distinguish between local peak and global peak, so it is impossible to track the GMPP using the conventional methods under partial shading condition.

In recent years, many scholars proposed different modified algorithms and artificial intelligence approaches on the area in order to suitable for MPPT under partial shading. Among them, the authors employed an improved variable step P&O method based on the global scan to achieve the global MPPT [4]. However, this proposed method needs to scan the entire P-V curve, so the rate of convergence is slow. Two-step method is proposed in [5]. The first step is to estimate the range of the global peak by measuring the open circuit voltage and short circuit current, and the second step is to locate the accurate GMPP. In fact, the essence of MPPT is the optimal problem of complex non-linear objective functions, so it is an alternative method to employ swarm intelligent optimum algorithms, such as particle swarm optimization (PSO) algorithm [6], artificial fish swarm algorithm (AFSA) [7], artificial bee colony (ABC) algorithm [8] or shuffled frog leaping algorithm (SFLA) [9] and so on. Among the evolutionary algorithms, PSO has been applied to search GMPP by many researchers in the PV systems, due to its simple principle, fast convergence and improved performance to deal with multi-modal and non-linear function search. The authors in [10] have added various extra coefficients in the traditional PSO update equations, which is helpful to improve the searching ability of particle swarm. Then, it also increases the computational burden of the algorithm. The literatures [3] employed PSO to locate the GMPP, then used HC to track the GMPP. The algorithms can achieve global MPPT rapidly and reduce output disturbance at the steady state. However, these papers does not analyze the algorithm restarting when environment occurrences variety.

Based on the above analysis, this paper proposes an improved PSO algorithm and variable step P&O method for MPPT control in PV systems. In the proposed method, the first step of the method is using the improved PSO algorithm to search for the approximate GMPP. Thus, the variable step P&O method tracks the accuracy GMPP dynamically, which can avoid the GMPP change step-by-step caused by the environmental transformation before the algorithm restarting. In conclusion, simulation results show the proposed method is very effective to deal with the MPPT problem under partial shading conditions.

2 MODELING OF PV CELL

PV cell is the basic unit of PV system, and it is necessary for better study on MPPT control of PV system to establish the

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precise and practical model of PV cell. Among various modeling methods of PV cell, the single diode model of PV cell [11] has been widely adopted, as depicted in Figure 1. According to Kirchhoff's current law, the output current of the PV cell can be described as

$$I = I_{sc} - I_0(\exp\left[\frac{q(V+IR_s)}{AkT}\right] - 1) - \frac{V+IR_s}{R_{sh}} \tag{1}$$

where V is the output voltage of PV cell, I_{sc} is the current generated by the incidence of light, I_0 is the reverse saturation currents of diode, and R_s and R_{sh} are the equivalent serial and paroled resistances, q is the electron charge (1.6×10^{-19}C), k is the Boltzmann constant (1.38×10^{-23}J/K), A represents the diode ideality constants, and T is the absolute temperature in Kelvin, respectively.

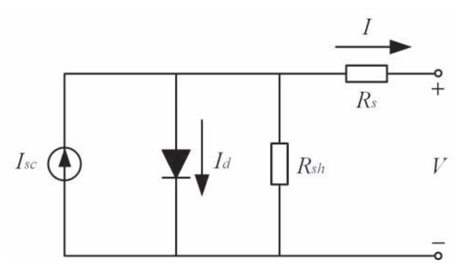

Fig 1. The single diode model of PV cell

The (1) above is the formula based on the physical principle of PV cell, and it has been broadly applied to the theoretical analysis of PV cell. Moreover, the parameters in the PV cell model are difficult to determine in practice, so the single diode model of PV cell is inconvenient for project application. According to the literature [11], the (1) makes the approximate substitution by the following three points: 1) neglected the ($V+IR_s/R_{sh}$) factor; 2) under open circuit state, I=0, $V=V_{oc}$; 3) at the maximum power point, $V=V_m$, $I=I_m$. Based on these, the engineering analytical model of PV cell can be obtained, and it only needs take into account short circuit current I_{sc}, open circuit voltage V_{oc}, peak power current I_m, and peak power voltage V_m. The engineering analytical model is described as

$$I = I_{sc}(1 - C_1\left\{\exp\left[\frac{V}{(C_2V_{oc})}\right] - 1\right\}) \tag{2}$$

where

$$C_1 = (1 - \frac{I_m}{I_{sc}})\exp\left[\frac{-V_m}{(C_2V_{oc})}\right] \tag{3}$$

and

$$C_2 = (\frac{V_m}{V_{oc}} - 1)\left[\ln\left(1 - \frac{I_m}{I_{sc}}\right)\right]^{-1} \tag{4}$$

3 PROPOSED MPPT ALGORITHM

In this section, we introduce the detailed methods for MPPT control. The improved PSO algorithm can rapidly search the GMPP, and the variable step P&O method sets the GMPP as the initial position to track the accuracy GMPP dynamically. The proposed algorithm is helpful to enhance efficiency and minimize errors for the MPPT problem under partial shading conditions.

3.1 Traditional PSO Algorithm

PSO is an evolutionary computation technique proposed by Dr. Kennedy and Dr. Eberhart in 1995 [6]. PSO algorithm originates in the behavior bird flocks and is used to solve the optimization issues, and in PSO particles, each particle represents a potential solution, which is corresponding to a fitness values based on fitness function. Assuming in a space, there are S partials, among them, the i_{th} particle velocity and position are respectively denoted by V_i and X_i. In the iterative process, the position of particles is influenced by the information of its own individual extremum P_i and global extremum P_g. The update formulas are written as follows:

$$V_i^{k+1} = \omega V_i^k + c_1 r_1\left(P_i^k - X_i^k\right) + c_2 r_2\left(P_g^k - X_i^k\right) \tag{5}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{6}$$

where ω is the inertia weight, c_1 and c_2 are the acceleration factors, r_1, $r_2\in(0, 1)$, and k is the currently iterative order. In order to prevent the particles to search blindly, the particles velocity and position are limited in [V_{min}, V_{max}] and [X_{min}, X_{max}].

3.2 Improved PSO Algorithm

Although the traditional PSO algorithm can have good performance in most cases, there are still some defects needed to solve, such as prior low precision, slow late convergence and relapsing into local optimization. This paper improves the traditional PSO algorithm, to ensure that PSO is reliably and simplified for MPPT control of PV systems. Among the swarm intelligent optimum algorithms, SFLA is a metaheuristic algorithm, which is inspired by frog leaping, and incorporated the memetic evolution into it [9]. The SFLA algorithm uses multi-swarm to evolution, and the convergent speed of SFLA is effective and reliably. Hence, according to the problems of the basic PSO, the grouping idea of SFLA is introduced in the basic PSO algorithm, ensuring the differences among particles and the searching of global extremum. In this paper, based on the fitness order, the particle swarm is divided into several groups. At the same time, the update formulas and tactics of PSO need to be adjusted as follows:

1) In each group, the speed and position of other particles are adjusted by the best value within group, and the equations can be written as

$$V_n^{k+1} = \omega V_n^k + c_1 r_1\left(P_m^k - X_n^k\right) \tag{7}$$

$$X_n^{k+1} = X_n^k + V_n^{k+1} \tag{8}$$

where P_m is the best position of particles in the m_{th} group, m=1, 2, …, M, M is the number of groups, and n=1, 2, …, N-1, N is the number of particles within group.

2) For the optimum particles of groups, the speed and position of particles are updated by the global best value, and the formulas are written as

$$V_m^{k+1} = c_2 r_2 \left(P_g^k - P_m^k \right) \tag{9}$$

$$P_m^{k+1} = P_m^k + V_m^{k+1} \tag{10}$$

where P_g is the best position of particles in the entire swarm. In the iterative procedure, when the best values within group is equal to the global best value, the (P_g-P_m) in (9) is zero. As the result, the particle will be unchanged. To avoid such situation, a small perturbation constant is allowed to add in (9).

3.3 Variable Step P&O Method

The traditional P&O method is used to track the GMPP by regulating the output voltage or the duty cycle. This method with principle simple and easy to realize has been the most popular technology for MPPT control in PV systems. The process of P&O method is as follows: firstly, an initial operating point needs to be set, which is often set at 0.78 fold of the open circuit voltage, the output current and voltage of PV array are measured and calculated the output power; then, after a fixed step disturbances the output voltage, the output current and voltage are measured to calculate the output power again. If the output power now is greater, it means the disturbance direction is correct; on the contrary, the disturbance direction needs to be changed. The traditional P&O method adopts a general fixed step, and if the step is too long, it is easy to result in significant oscillation around the GMPP; otherwise, a small step may lead to the slow tracking speed of MPPT control.

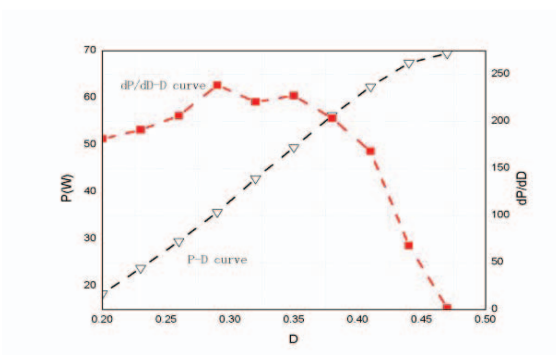

Fig 2. The partial P-D curve and dP/dD-D curve of PV array

In order to solve the contradiction between the tracking speed of conventional P&O method and the tracking accuracy of the steady state, this paper proposes an adaptive variable step P&O algorithm. In fact, the MPPT control is always regulated by the duty cycle, so this algorithm selects the duty cycle (D) as the disturbance constant. Though the simulation system described in the fourth section, the partial P-D curve and the dP/dD-D curve of the PV array are shown in Figure 2.

According to the output characteristics of the P-D curve and dP/dD-D curve, the perturbation expression of duty cycle can be constructed as

$$\Delta D = \alpha \frac{P - P_{old}}{D - D_{old}} \tag{11}$$

where α is an empirical value, called the adaptive factor, and the value of parameter α can be estimated by the following equation:

$$\alpha \approx \frac{D_{step}}{|\mathrm{dP/dD}|_{\max}} \tag{12}$$

where $|\mathrm{dP/dD}|_{\max}$ is the maximum value in the dP/dD-D curve, and D_{step} is an initial step length. Actually, the (12) only calculated the approximate value of parameter α, and the final value needs be adjusted by experiments.

3.4 The Restart Condition of Algorithm

The GMPP of PV array is greatly influenced by the insolation and temperature, so it is necessary to restart the algorithm to track the GMPP again and void influence due to the global peak changing to the local peak gradually. At present, the most PV systems apply the timing restart. However, this way is lack of flexibility, and frequent auto restart result in amount of power consumption. The proposed method in this paper can realize dynamic tracking of the GMPP of PV array under uniform illumination conditions, so it is needless to restart in this case. For this reason, this algorithm determines whether the PV system needs restart by the following conditions. Firstly, based on the influence of the basic output power of PV systems by the weather conditions [12], it is possible to determine whether the PV array is under partial shading conditions. When the actual output power is less than the theoretical value calculated by the (13), it shows that the PV array is under the non-uniform illumination conditions.

$$P_{real} < P_{pv} \left(\frac{G}{G_{STC}} \right) [1 + \alpha_p (T - T_{STC})] \tag{13}$$

where P_{real} and P_{pv} are respectively the actual output maximum power and the rated power of PV module, G is the actual solar insolation, G_{STC} is the insolation (1000W/m^2) under the standard test condition, α_p is the temperature coefficient of power of PV module (-0.35%/°C), T represents the actual temperature of the PV module, and T_{STC} is the temperature (25°C) under the standard test condition.

Under partial shading condition, when the change of the output power is great, the restart will run for MPPT control again. In this paper, the restart condition is set

$$\frac{|P_{real} - P_m|}{P_{pv}} > \Delta P \tag{14}$$

where P_m is the power recorded, and ΔP is the change rate of the output power. The value of ΔP may be set as 5% based on the simulation results.

3.5 Overall Structure of Proposed Algorithm

This proposed MPPT control method uses the improved PSO to rapidly search the approximate global maximum power point. At the particles initiation, the random particles result in the PV systems in the unstable state. Then, based on the analysis of PV system determine the range of the duty cycle correspond to the GMPP, the distribution of the particles are uniform defined in the limited range. In this paper, the output power P is selected as the fitness value. The velocity and position of the particles can be updated using the (7)-(10).

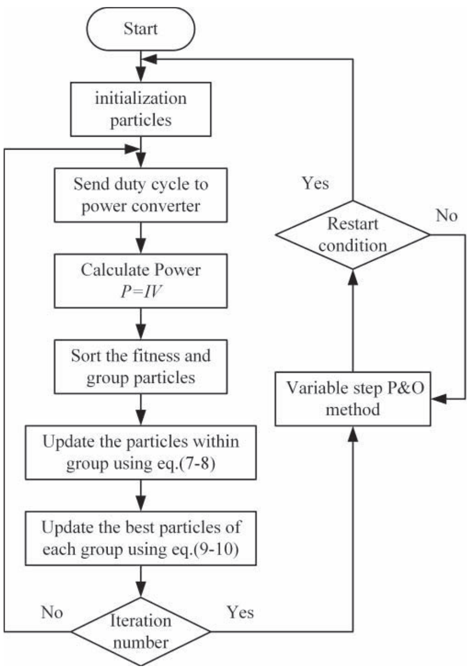

Fig 3. The complete flowchart of the proposed method

At steady state, in order to avoid the complex calculations of the PSO algorithm, the variable step P&O tracks the accuracy GMPP dynamically. The restart will run if needed. The detailed step about the block diagram of proposed algorithm is shown in Figure 3.

4 SIMULATION STUDIES

To evaluate the proposed method, the Buck-Boost converter is utilized. This converter is designed with the following parameters: inductor L=800μH, input capacitance C_1=100μF, output capacitance C_2=220μF, resistance R_{load}=20 Ω, and 20 kHz switching frequency. The PV array includes two PV panels shown in the second section which are connected in series. The parameters of single simulation PV panel under the standard test condition (STC: Temperature=25°C, Air mass=1.5, and Insolation= 1000 W/m^2) are set as follows: V_{oc}=21.6V, I_{sc}=2.25A, V_m=17.6V, I_m=1.98A, and peak power P_m=35W. Fig.4 shows the block diagram for the PV array with the Buck-Boost converter.

In order to check the effectiveness and superiority of the proposed method under partial shading, the contrastive simulation and experiment between the proposed method and traditional PSO algorithm for PV system is designed. The Table1 shows the basic parameters of the traditional and proposed PSO algorithm, included inertia weight ω, acceleration factors c_1 and c_2, number of partials S, number of groups M, and maximum iterative number K, and this improved PSO algorithm is flagged as IPSO. Due to change in the update equations, the parameters of the proposed algorithm are smaller compared with the basic PSO algorithm.

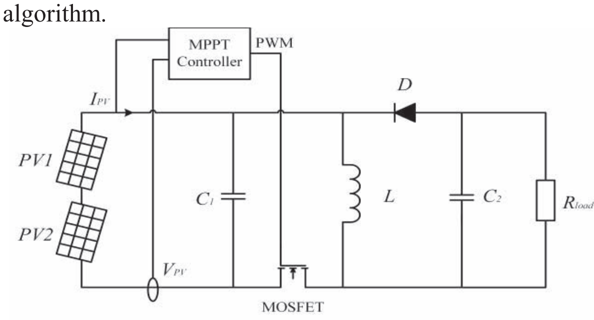

Fig 4. The block diagram for the PV array with the Buck-Boost converter

Table1. Basic Parameters

	c1	*c2*	*w*	*S*	*M*	*K*
PSO	1.2	1.2	0.8	6	--	3
IPSO	0.6	0.8	0.5	6	2	3

For simulating the different shading situation for the PV array, the insolation of the second PV panel occurs to change suddenly from 1000W/m^2 to 700W/m^2 at 0.3s in the process of simulation. Fig.5 shows the different P-V curve of PV system under unequal insolation conditions, and the maximum power is decreased significantly from 70W to 52.3W.

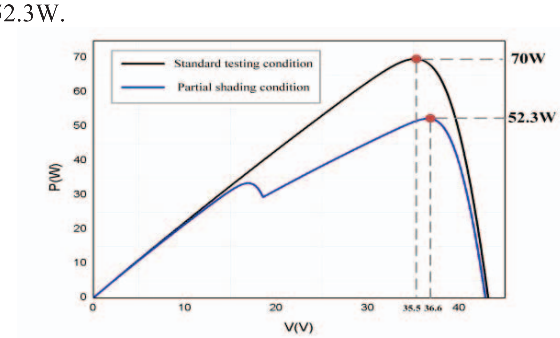

Fig 5. P-V curve for different irradiation levels

The simulation results for power and duty cycle are shown in Figure 6 and Figure 7. In the beginning, under full lighting state, PV system employs the PSO algorithm to search the global peak, and six particles evenly distributed ensure the reliability of searching process. At 0.3s, the insolation is suddenly stepped down to 700W/m^2. At this time, satisfied the restart conditions, the proposed method restarts for MPPT control.

Figure 6 shows the simulation results of the traditional PSO algorithm without group tactics. The results indicate that this method has some defects in the slow convergence speed of the particles and significant oscillations during the searching process. After about 0.15s searching, this algorithm found the best duty cycle 0.481, and the best fitness 69.6W, and the relative error is 0.57% compared with the theoretical value 70W. And after auto restarting under partial shading, the traditional PSO algorithm searched the best duty cycle 0.39. The actual output power is 52.1W, and the relative error is 0.38%.

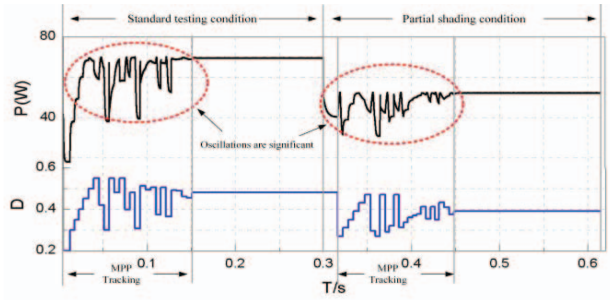

Fig 6. The simulation results of traditional PSO algorithm

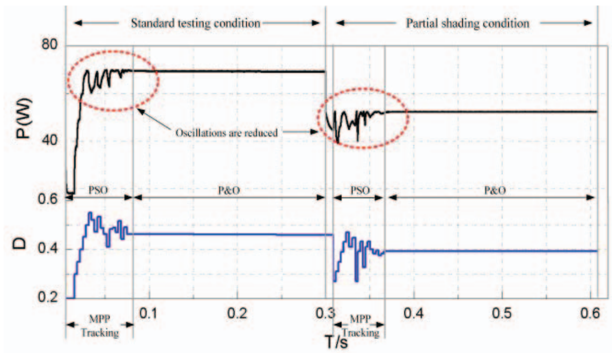

Fig 7. The simulation results of proposed method

Figure7 shows the simulation results of the improved method for MPPT control. Compared with traditional PSO algorithm, the improved PSO algorithm with the group idea has the advantage of the fast convergence speed and the reduction of the power oscillations during the searching process, which is beneficial to reduce power losses and increase system efficiency. The searching time of the improved PSO algorithm is about 0.08, which is shorter than the basic algorithm. Under the full lighting condition, the best duty cycle is 0.462, and the actual maximum power is 69.9 W, and the relative error is 0.14% compared with the theoretical value. After the insolation is stepped down to 700W/m^2, the improved PSO algorithm found the best duty cycle 0.383, and the output power is 52.3W similar with the theoretical value. At the steady state, the adaptive variable step P&O method tracks the accuracy GMPP dynamically. The simulation results show that this method combining improved PSO algorithm and variable step P&O is superior in the convergence speed and the output stability under the complex environment conditions. This method can locate the precise GMPP, reduce the oscillation and increase the output power effectively.

5 CONCLUSION

In this paper, we proposed an improved PSO algorithm and variable step P&O method for the MPPT control in PV system under partial shading condition. In the proposed method, the grouping idea of SFLA is introduced in the basic PSO algorithm, ensuring the fast convergence speed. Furthermore, the variable step P&O method is obtained by the improved parameters based on the output characteristics curves of the P-D and dP/dD-D. Finally, numerical simulation experiments were performed to compare the proposed method with the traditional PSO algorithm for MPPT under the same parameter settings, and experimental results show that the proposed method with appropriate parameter outperforms the PSO algorithm in most cases. This paper only analyzes and applies the simulation of the proposed method, so we will continue optimizing the proposed algorithm and completing the verification of the hardware platform further.

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