Research on Photovoltaic Array MPPT Based on IPSO-IP&O Hybrid Algorithm

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ABSTRACT

In photovoltaic power generation systems, there is a problem of shadow shading in photovoltaic cell arrays, resulting in multiple power peaks on their output power voltage curve. At this time, PSO algorithm in Maximum Power Tracking (MPPT) has the disadvantages of slow convergence speed and easy occurrence of premature convergence. This article proposes a hybrid algorithm (IPSO-IP&O) that combines IPSO and Variable Step Size Disturbance Observation (IP&O). Firstly, the IPSO algorithm introduces nonlinear dynamic parameters through adaptive parameter to meet the different needs of MPPT in the early and late stages, track it more quickly, and reduce the possibility of getting stuck in local optimal solutions; Then, the global optimal solution output by the IPSO algorithm is further tracked using the IP&O algorithm to improve accuracy and reduce power oscillations. Using MATLAB/Simulink to simulate the system, and the results show that the IPSO-IP&O algorithm can effectively improve the convergence speed and accuracy of system optimization under shadow occlusion conditions.

Keywords: Photovoltaic power generation; Local shadows; Maximum power point tracking; IPSO algorithm； Variable step perturbation observation method.

1. INTRODUCTION

Solar energy, as a sustainable and clean energy source, is favored by countries around the world. The power optimizer is equivalent to installing a DC/DC converter at the output end of each photovoltaic cell, which can ensure the MPPT in real time while fully utilizing electrical energy. At the same time, it is small in size, low in cost, and high in safety factor. Therefore, it has received widespread attention in recent years. The series topology design makes the input and output voltages of the power optimizer close, improving circuit efficiency while reducing costs.

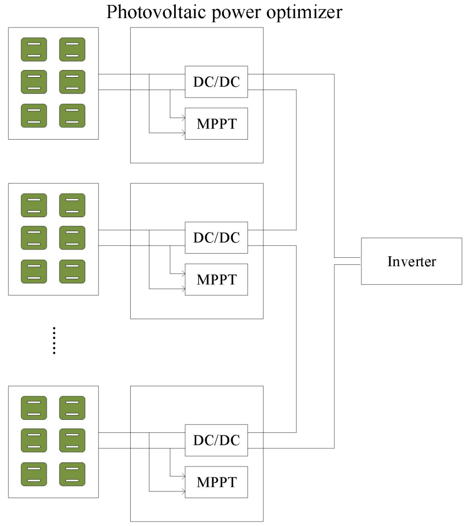

Figure 1. Schematic diagram of the solar energy aircraft energy system.

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The output power of photovoltaic arrays is affected by factors such as temperature and light intensity. In order to efficiently utilize solar energy, it is necessary to ensure that the photovoltaic array always outputs at maximum power. Therefore, in the design process of photovoltaic cells, maximum power tracking (MPPT) must be achieved. In practical work, when the photovoltaic array is partially obstructed by surrounding buildings or buildings, multiple power peaks appear on its output power voltage curve, leading to traditional MPPT algorithms falling into local optimal solutions in this situation. Therefore, studying the intelligent algorithm of multi peak MPPT is of great significance [1].

Scholars at home and abroad have proposed modifications to the traditional MPPT algorithm and intelligent optimization algorithms. Reference [2] proposes an improved perturbation observation method, which summarizes the distribution characteristics of local maximum power points and then uses perturbation observation method for local scanning of these areas. However, this method takes a long time to track the maximum power points and is not universal. References [3-5] use particle swarm optimization for multimodal MPP optimization, which has a fast convergence speed and is easy to implement. However, the PSO algorithm still has shortcomings, such as long convergence time and a decrease in search accuracy with increasing iteration times. Reference [6] proposed an adaptive inertia weight particle swarm optimization algorithm. However, only the influence of inertia weight on the algorithm is considered, and the learning factor is fixed, so the performance of the particle swarm algorithm is still not optimal. References [7-9] propose a hybrid algorithm combining PSO algorithm and P&O algorithm, and by comparing the current and voltage information stored during the convergence process of the algorithm, determine the shading situation and choose PSO or P&O. Due to excessive reliance on changes in power and voltage, it is easy to generate false positives, resulting in the algorithm converging to local optimal point (LMPP) and having a longer convergence time.

On the basis of existing research, this article proposes a hybrid algorithm (IPSO-IP&O) that combines Adaptive Parameter Particle Swarm Optimization (IPSO) and Variable Step Size Disturbance Observation (IP&O). The IPSO algorithm first uses nonlinear strategies to adaptively adjust the inertia weight and learning factor, and quickly and accurately find the global optimal solution (GMPP) among numerous local optimal solutions. Then, the IP&O algorithm is used for precise tracking to reduce power fluctuations in steady-state. The IPSO-IP&O algorithm has been proven to have faster convergence speed and accuracy under local shadow occlusion through MATLAB/Simulink simulation.

2. EQUIVALENT CIRCUIT AND OUTPUT CHARACTERISTICS OF PHOTOVOLTAIC CELLS

2.1 Mathematical model of photovoltaic cells

The common equivalent circuit of photovoltaic cells is shown in Figure 2.

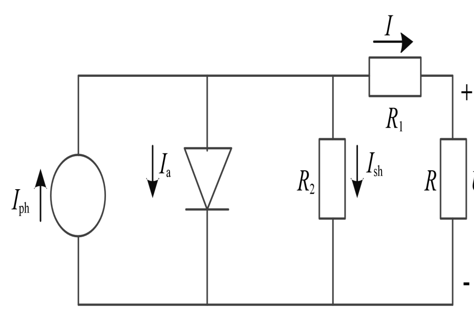


Figure 2. Equivalent circuit of photovoltaic cells.

Using the engineering model in reference [1], the output can be described as follows:

$$I_{pv} = I_{pc} - I_o[\exp(\frac{q}{n_c K_c T} V_{pv}) - 1] \tag{1}$$

$$P = UI_{pc}\{1 - c_1[\exp(\frac{U}{c_2 U_{oc}}) - 1]\} \tag{2}$$

In this equation, $c_1 = (1 - \frac{I_{m1}}{I_{pc1}})\exp(\frac{-U_{m1}}{c_2 U_{oc1}})$, $c_2 = (\frac{U_{m1}}{U_{oc1}} - 1)[\ln(1 - \frac{I_{m1}}{I_{pc1}})]^{-1}$, I_{m1}, U_{m1} and U_{oc1} is the maximum power point current, voltage, and open circuit voltage under any condition.

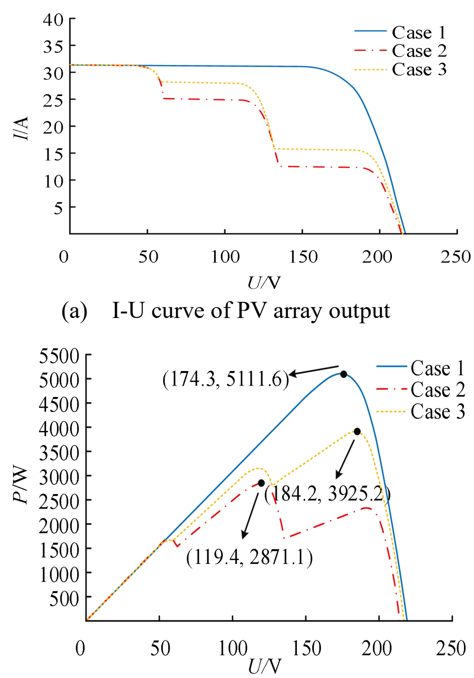
2.2 Modeling the Output Characteristics of PV Arrays under Local Shadows.

A PV array comprises a series of solar cells connected in parallel and series. In the presence of uneven shading, the "hotspot effect" on the array surface can potentially damage the cells. To safeguard against this, a diode is typically parallel-connected at both ends of the cell to act as a bypass. However, this may lead to the occurrence of multiple peaks in the output $P-U$ curve.

In the case of local shadows, modeling employs three PV arrays to study and analyze their multi-peak characteristics. The parameters of the cells used in each array are identical. Simulations are conducted at a standard ambient temperature of 25℃ under different shading conditions for the three cases listed in Table 1. Figures 3(a) and 3(b) display the $I-U$ and $P-U$ characteristic curves of the PV array output for the three cases.

Table 1. Three different types of solar irradiance for photovoltaic arrays.

Case	Solar irradiance /(W·m^{-2})		
1	1000	1000	1000
2	1000	800	400
3	1000	900	700



(a) I-U curve of PV array output

(b) P-U curve of PV array output

Figure 3. I-U and P-U curves of photovoltaic array output.

Figure 3(b) illustrates that under uniform solar irradiance in Case 1, the $P-U$ curve of the three PV arrays exhibit only a single peak power point. However, in Cases 2 and 3, where varying solar irradiance conditions are considered, multiple peak power points emerge.

3. RESEARCH ON MPPT METHOD

3.1 Traditional PSO algorithm

Particle Swarm Optimization (PSO) is a process based on the study of collective predation behavior of birds, which leads to a large number of examples that iteratively change their positions within a certain space and ultimately find the optimal solution. This algorithm is an intelligent algorithm that can optimize multi peak functions. The iterative formula of particle swarm optimization algorithm is as follows:

$$v_i^{k+1} = wv_i^k + c_1 r_1 (P_{besti} - x_i^k) + c_2 r_2 (G_{besti} - x_i^k) \tag{3}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{4}$$

$$P_{besti} = \begin{cases} P_{besti} & f(x_i^{k+1}) \geq f(P_{besti}) \\ x_i^{k+1} & f(x_i^{k+1}) \leq f(P_{besti}) \end{cases} \tag{5}$$

$$G_{best} = \begin{cases} G_{best} & f(x_i^{k+1}) \geq f(G_{best}) \\ x_i^{k+1} & f(x_i^{k+1}) \leq f(G_{best}) \end{cases} \tag{6}$$

In the given formulas, V represents the initial velocity, X represents the initial position, ω is the inertia weight, c1 and c2 are the learning factors, k is the iteration count of particles, r1 and r2 are random numbers within the (0, 1) range, f is the particle's adaptive function, Gbest is the global best particle position, and Pbest is the individual best particle position.

Traditional PSO algorithms often suffer from a rapid loss of particle diversity, leading to premature convergence and the inability to guarantee convergence to the global optimum.

3.2 Improved particle swarm optimization algorithm

The inertia weight ω and learning factors c1 and c2 play pivotal roles in determining the global search capacity and the speed at which particles navigate towards individual and global optimum positions. PSO algorithms often assign fixed values to ω, c1, and c2 based on empirical observations, potentially causing an imbalance between local and global exploration during the optimization process. This research applies a nonlinear control strategy into the determination of ω, c1, and c2. The dynamic formulas are expressed as follows:

$$\omega_k = \omega_{\max} - (\omega_{\max} - \omega_{\min}) \sin[(\pi / 2) \cdot (k_i / k_{\max})] \tag{7}$$

$$c_1 = 0.9 \exp(1 - \frac{k_i}{k_{\max}}) \tag{8}$$

$$c_2 = 0.6 \exp(\frac{k_i}{k_{\max}}) \tag{9}$$

3.3 IP&O algorithm

The P&O perturbation observation method is one of the commonly used MPPT methods, which is easy to implement and simple. This method mainly samples the PV system and optimizes it by comparing and calculating the output power before and after disturbance. The formula is as follows:

$$\begin{cases} P = U_{pv} I_{pv} \\ \Delta P = P(i) - P(i-1) \end{cases} \tag{10}$$

In the formula: U_{pv} , I_{pv} represent the output of the PV system; $P(i-1)$ and $P(i)$ represent the power values before and after the i-th disturbance; ΔP represents the power increment before and after disturbance. If the disturbance is positive, ΔP perturbs in the same direction next time; if the disturbance is negative, ΔP perturbs in the opposite direction next time.

For traditional P&O perturbation methods, the step size is usually a constant value. If the step size is set too small, it will reduce the search speed and lead to a long convergence time; conversely, it will cause significant fluctuations at the MPP, reducing the accuracy of the search. Therefore, this article adopts an adaptive variable step size method, introducing a step size shrinkage factor to keep the step size within a reasonable range and accelerate the algorithm's fast tracking to MPP. The recommended formula for the change in step size is:

$$\lambda_{step} = \varepsilon \left| \Delta p \right| \tag{11}$$

In the formula, λ_{step} represents the step size, and ε represents step size scaling factor.

When using the IPSO algorithm for global optimization in the early stage, it has already iterated to the vicinity of GMPP. At this point, switch to the IP&O perturbation observation method, which utilizes its excellent local search characteristics to reduce convergence time and provide more stable output.

3.4 IPSO-IP&O hybrid algorithm

Initially, the positions and speeds of particles are initialized. Subsequently, the voltage and power outputs of PV system are considered as variables and objective functions, respectively. The primary goal is to determine the MPP. The improved PSO algorithm, as outlined in this research, is applied in the context of MPPT, following the algorithmic flow depicted in Figure 6. During the particle swarm search, the algorithm compares the objective function values of each particle, selecting the adaptive value of the optimal particle, and storing it in Pbest. Then, the objective function value and position of the best individual from Pbest are placed into Gbest. The positions and speeds of particles are updated based on specific equations. Additionally, the current objective function values of each particle are compared with the previous Pbest. The particle swarm Gbest is determined based on the optimal Pbest. Throughout each iteration, the weighting coefficients and learning factors are updated.

Then switch to the IP&O perturbation observation method, utilizing its excellent local search characteristics to reduce convergence time while also providing more stable output.

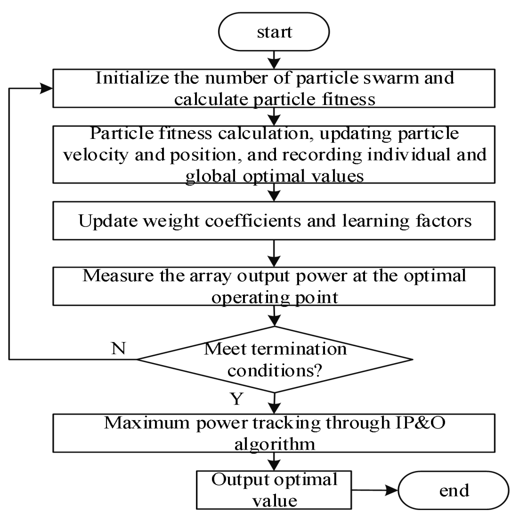


Figure 4. IPSO-IP&O algorithm process.

4. SIMULATION VERIFICATION

4.1 Simulation Model and Parameters

The photovoltaic control system is built in MATLAB/Simulink based on the improved PSO algorithm, depicted in Figure 6. The system comprises three PV arrays, a MPPT controller, a Four Switch Buck-Boost converter, and a load. The circuit parameters are defined as follows: Cin= 660uF, Cout= 660uF, L= 9uH, RL=10Ω. An analysis is conducted for photovoltaic MPPT under two scenarios: static and dynamic shading. The objective is to compare the tracking accuracy and speed of both the traditional PSO algorithm and the IPSO-IP&O algorithm. In the PSO algorithm, parameters are set as ω=0.7, c1=1, c2=1. For the IPSO-IP&O algorithm, ωmax = 0.8, ωmin = 0.2, λstep= 0.5, the number of particles is fixed at 6, and the maximum iteration count is set to 10.

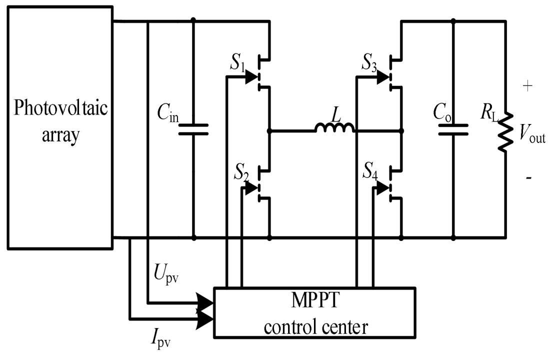


Figure 5. Photovoltaic MPPT control system.

4.2 Simulation under Local Shadows

The simulation results depicted in Figure 5 showcase MPPT using both the PSO algorithm and the IPSO-IP&O algorithm. The light intensities for the three PV cells are designated as S1=600W/m2, S2=800W/m2, and S3=1000W/m2, while the maximum power is denoted as Pm=931.0W.

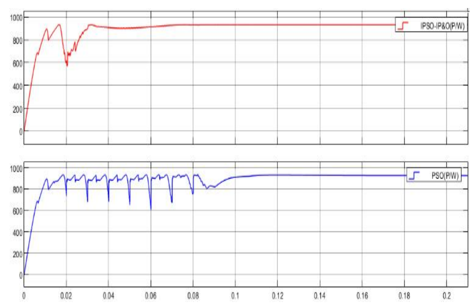


Figure 6. The output power of photovoltaic arrays under shadows controlled by two algorithms.

From Figure 6, it shows that both the PSO algorithm and the IPSO-IP&O hybrid algorithm proposed in this paper can ultimately track the maximum power point with good stability. The traditional PSO algorithm gradually stabilizes the system after 0.11 seconds, and the output power continues to fluctuate around 926.0W. The IPSO-IP&O hybrid algorithm proposed in this article begins to converge around 0.06s, and the stable output power remains fluctuating around 930.9W. In the case of static local shadows, compared with the basic PSO algorithm, the IPSO-IP&O hybrid algorithm proposed in this paper has significantly improved tracking speed and better stability.

5. SUMMARY

This article proposes a hybrid algorithm (IPSO-IP&O) that combines IPSO and IP&O to address the performance shortcomings of PSO algorithm in tracking the maximum power point. According to the different requirements in the early and middle stages of the optimization process, the inertia weight in the early stage of the optimization process ω And the learning factor c1 is relatively large, while the learning factor c2 is relatively small; Inertia weight in the later stage of optimization process ω And the learning factor c1 is relatively small, while the learning factor c2 is relatively large. Then, IP&O algorithm is used to avoid getting stuck in local optimal solutions and reduce power fluctuations. The IPSO-IP&O algorithm has been proven to have faster convergence speed and accuracy under local shadow occlusion through MATLAB/Simulink simulation.

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