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APPLICATION OF PARTITIONED SELF-ADAPTION VARIABLE STEP SIZE MPPT ALGORITHM IN PV SYSTEM

Geng Chen, Xiucheng Dong, Sha Dai, Haoran Li and Ke Peng

School of Electrical Engineering and Electronic Information
Xihua University
No. 999, Jinzhou Road, Jinniu District, Chengdu 610039, P. R. China
crznh177@163.com

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Abstract. *In order to relieve the shortage of perturb and observe (P&O) method in starting time, steady-state performance and disturbance direction while the ambient conditions change sharply, and to avoid the complexity of traditional variable step size method in determining step value, the paper proposes a partitioned self-adaption variable step size MPPT algorithm, the paper firstly combines the difference value of two adjacent power sampling with the output characteristic of PV cells to determine a two-dimensional plane, then determines the next step changed vector of the controller through a specific step length calculation formula according to the specific area where the control object is located, and finally achieves the goal of lower computation costs, faster starting time, better steady-state performance and faster dynamic response when the light intensity or the ambient temperature changes rapidly. The simulation results verify the correctness and the validity of the proposed algorithm.*

Keywords: Photovoltaic cell, Maximum power point tracking, Partitioned self-adaption variable step size, Perturbation and observation

1. **Introduction.** The world's energy crisis and environmental pollution are getting worse. Solar photovoltaic (PV) power generation as a new energy becomes one of the most popular energy because of its clean, pollution-free, low maintenance costs and inexhaustible characteristics [1]. However, now the factors that the energy conversion efficiency of PV power generation is low and the energy loss is high, have become a major obstacle which restrict people to popularization and large-scale application. Therefore, the thing about how to improve the energy conversion efficiency and reduce the energy cost have become the research hotspot of many scholars.

Due to the fact that the P-U and I-U characteristic curves of solar PV cells are nonlinear, and it is a function of ambient temperature (T) and light intensity (R), in order to use maximumly solar energy and improve the energy converted efficiency, the maximum power point tracking (MPPT) control is required in photovoltaic power generation system. MPPT control method proposed at home and abroad mainly has: the constant voltage tracking (CVT) method, the perturb and observe (P&O) method, the incremental conductance (IC) method, the fuzzy control (FC) method and the artificial intelligence (AI) method, etc. However, these methods still have many insufficiencies; for example, the efficiency of energy conversion is still low or the calculation of the algorithm is complex. P&O (Firstly, perturb the output voltage of the PV array, then, calculate the output power of the PV array before and after the perturbation according to P = UI, and finally compare the two output power before and after the disturbance) is used widely in industry because of its good balance between the efficiency and the calculation. However, it still has many problems, such as the difficulty to weigh the response time and the steady-state oscillation which is caused by fixed step length. [2-5] presented many self-adaption variable step size MPPT algorithms, the function of them used to determinate the duty cycle of the DC-DC converter in PV systems is complex, because of those function used several times the value of PV cell's P-U curve's first derivative or second derivative and imported many variable parameters. These acts increased the computation costs and the hardware requirements to the controller.

This paper proposes a partitioned self-adaption variable step size MPPT algorithm and makes a detailed theoretical analysis to the algorithm. When calculating the value of the variable step size, the novel algorithm just uses a division and three multiplications, so it can achieve the goal of lower computation costs and avoids the problem of computational complexity and high hardware requirements to the controller, which exist in traditional variable step size MPPT control algorithm. In order to verify the effectiveness of the algorithm, a comparative simulation study was carried out between the algorithm proposed in the paper and the conventional P&O. Simulation results show: compared with the P&O method, this algorithm proposed in the paper has the advantages of fast start-up, good steady-state performance and fast dynamic response when the ambient of the PV cells changed rapidly.

2. PV Array Model and Its Output Characteristics.

2.1. Mathematical model.
PV array is a device which uses the photoelectric effect of the semiconductor to directly convert the solar energy into electrical energy. The equivalent circuit model of PV cell is shown in Figure 1 [6]. I_{ph} is the current generated by the incident light, I_{d} is the reverse saturation or leakage current of the diode, R_{s} is the equivalent series resistance of the array, R_{sh} is the equivalent parallel resistance, and I_{PV} is the output current of PV array.

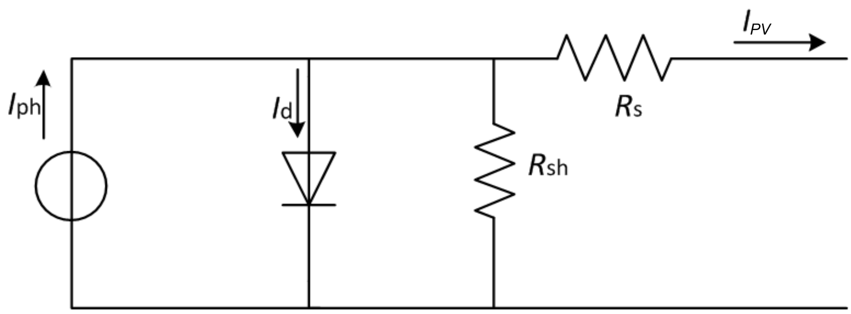


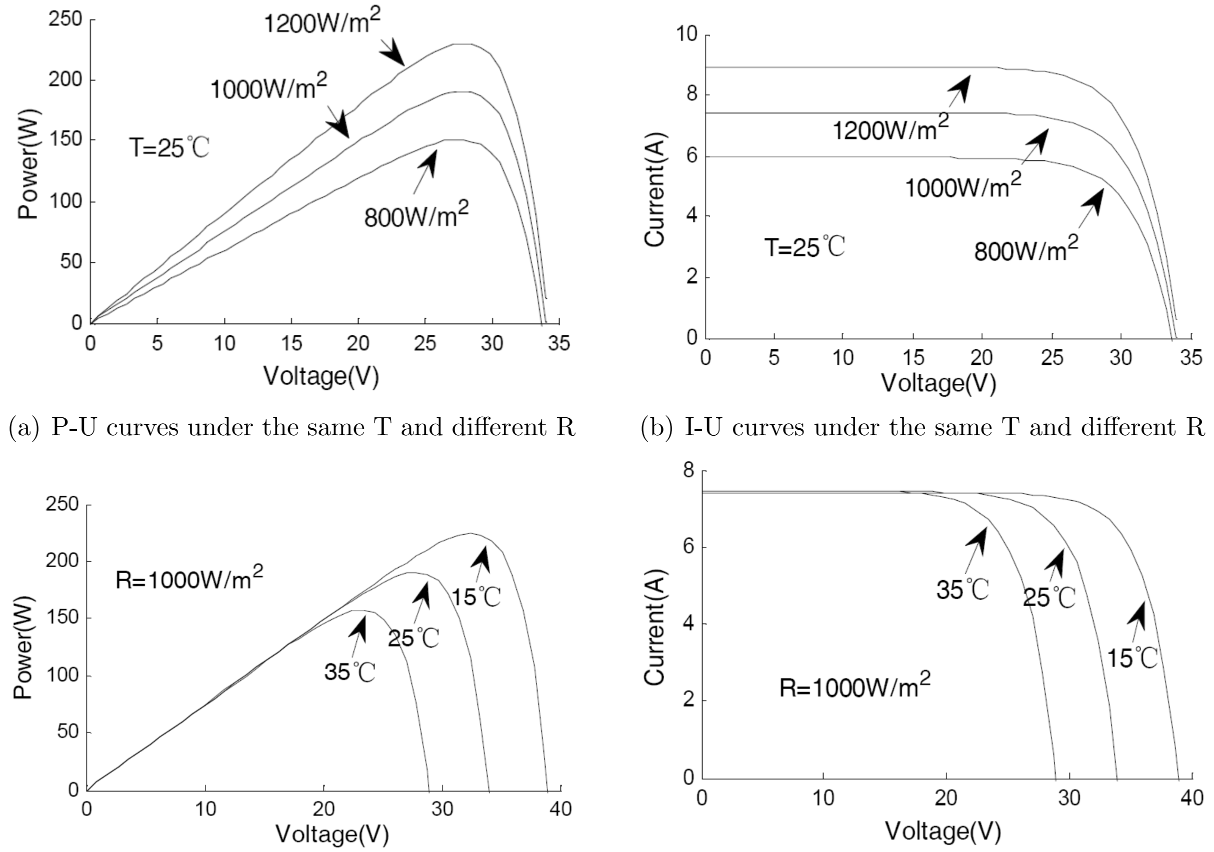
FIGURE 1. Equivalent circuit model of PV array

The I-U characteristic curve of the PV cell that changes because of the ambient temperature T (°C), light intensity R (W/m^2), and ageing of solar cells. $I = f(U, R, T)$. According to the theory of electronics, we can get the equivalent mathematical model of the PV array [5-8]:

$$I_{PV} = I_{\text{ph}} - I_{\text{d}} \left[\exp\left(\frac{U + R_{\text{s}} I_{PV}}{V_t \alpha} \right) - 1 \right] - \frac{U + R_{\text{s}} I_{PV}}{R_p} \tag{1}$$

where $V_t = N_S kT/q$ is the thermal voltage of the PV array with N_S cells connected in series; k is the Boltzmann constant, $k = 1.38 \times 10^{-23}$J/K; q is the electron charge, $q = 1.9 \times 10^{-19}$C; α is the ideal constant of diode; I_{d} is the leakage current or reverse saturation of the diode. If the PV array is composed of N_S parallel connections of cells, the leakage current and saturation currents may be expressed as $I_{\text{ph}} = N_S * I_{\text{ph\_cell}}$, $I_{\text{d}} = N_S * I_{\text{d\_cell}}$.

2.2. Characteristics curves.
According to the above mathematical expression, the paper sets up a simulation model in MATLAB/Simulink [7]. Figure 2 shows the I-U and P-U characteristic curves of PV cells. The curves under the same R (W/m^2) and different T (°C) or the same T (°C) and different R (W/m^2) are shown in Figure 2.



(a) P-U curves under the same T and different R (b) I-U curves under the same T and different R

(c) P-U curves under the same R and different T (d) I-U curves under the same R and different T

FIGURE 2. I-U and P-U curves of the PV cell

3. Partitioned Self-Adaptive Variable Step Size MPPT Algorithm.

3.1. **Operating principle.** The solar PV power generation system consists of PV array, Boost circuit, PWM controller and load device. MPPT is the key of the PWM controller. The input signal of the proposed MPPT algorithm is dP and *step*, and dP is determined by Equations (2) and (3). The value of *step* is obtained from the exact value of ΔP through a special equation shown in (4). The greater the absolute value of ΔP is, the greater the absolute value of *step* is; the smaller the absolute value of ΔP is, the smaller the absolute value of *step* is. When $\Delta P > 0$, $step > 0$; when $\Delta P < 0$, $step < 0$. $P(n)$ is the instantaneous output power of the PV array corresponding to the Nth sampling time.

$$\Delta P = P(n) - P(n-1) \tag{2}$$

$$dP = |\Delta P| \tag{3}$$

$$step = f(\Delta P) \tag{4}$$

Figure 3 shows the plane of dP-*step* and its six parts. When $dP < \delta$ it means dP locates at zone ③. Let the value of the variable step size ΔU be equal to zero at this time. The behavior can effectively suppress the large amplitude oscillation that happened in P&O method when the system reaches a steady state, and reduce the system energy loss, and improve the efficiency of PV arrays when converting solar energy. When the ambient conditions remain unchanged or little change, even if the value of the variable step size ΔU reaches to the maximum, the value of dP cannot be too large, so when this phenomenon that the value of dP which is too large occurs it means $dP > \varepsilon$ and locates in zone ④. It can be concluded that the ambient of the PV array is undergoing rapid and dramatic changes. At this time let the value of the variable step size ΔU be equal to zero to keep

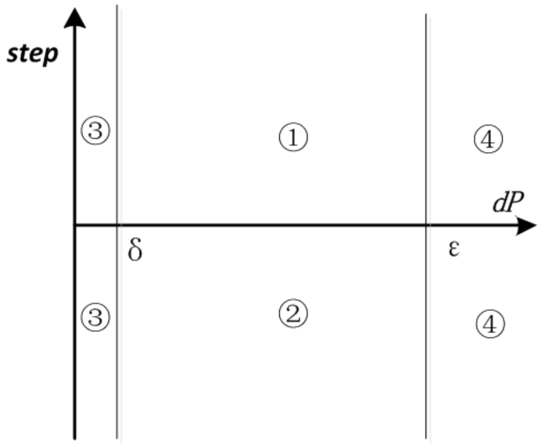


FIGURE 3. Plane of dP-$step$

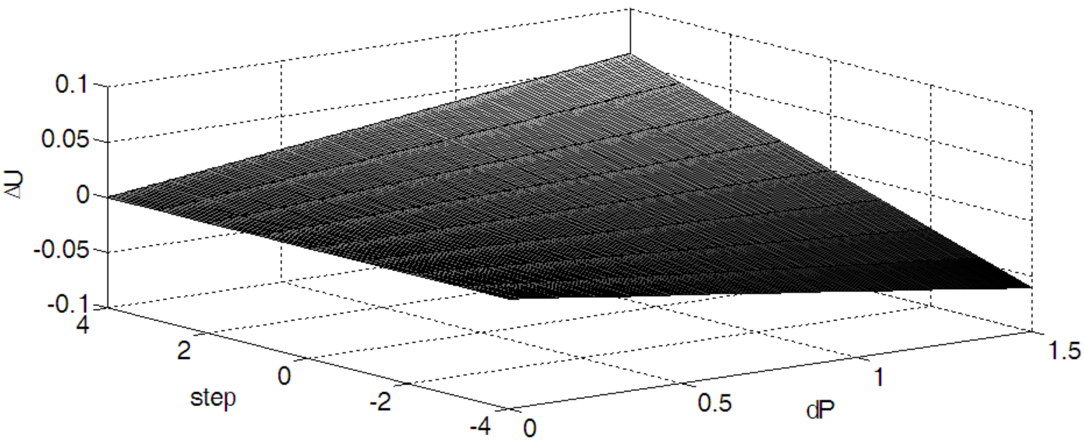


FIGURE 4. Proposed function for generating variable step size

the PWM signal unchanged. The behavior can effectively prevent the malfunction that happened in P&O method. Waiting for the conditions of the ambient become steady, the algorithm restarts to track the new maximum power point (MPP) again. The algorithm achieves the purpose of preventing PV system's malfunction and improves PV system's dynamic response capability through the above method. When the values of dP and $step$ are located in zone ①, the operating voltage of the PV array is on the left of the MPP, and the value of ΔU is positive and increases with increasing the product of dP and $step$; when the values of dP and $step$ are located in zone ②, the operating voltage of the PV array is on the right of the MPP, and the value of ΔU is negative and decreases with decreasing the product of dP and $step$. Compared with the P&O method, the algorithm proposed in this paper can better balance the system's response speed with the oscillation amplitude when the system is steady. Compared with the traditional variable step size method, the algorithm proposed in this paper is easier to implement and the requirements to hardware are lower.

The relationship among dP, $step$ and the variable step size ΔU is shown in Equation (5), where θ is the velocity factor, and in this paper $\theta = 0.01$. Figure 4 shows the three-dimensional diagram about Equation (5).

$$\Delta U = \theta \times step \times dP \tag{5}$$

3.2. **Workflow.** The controller collects the instantaneous voltage $U(n)$ and instantaneous current $I(n)$ of the PV array and calculates the instantaneous output power $P(n)$. Let the current instantaneous output power $P(n)$ subtract the previous acquired output power $P(n-1)$, and the difference is denoted by ΔP. The value of dP is obtained through Equation (3). According to the specific value of ΔP calculate the value of *step* through the designed *step* generation function. Then the controller determines the value of the real-time perturbation variable step ΔU by Equation (4), and uses the value of ΔU to adjust the modulation signal of PWM control generator. The controller achieves the purpose of real-time tracking MPP by changing the PWM signal. The specific algorithm flow chart is shown in Figure 5, where $\delta = 0.3$, $\sigma = 0.4$, $\tau = 0.5$, $\upsilon = 0.6$, $\varepsilon = 1.5$.

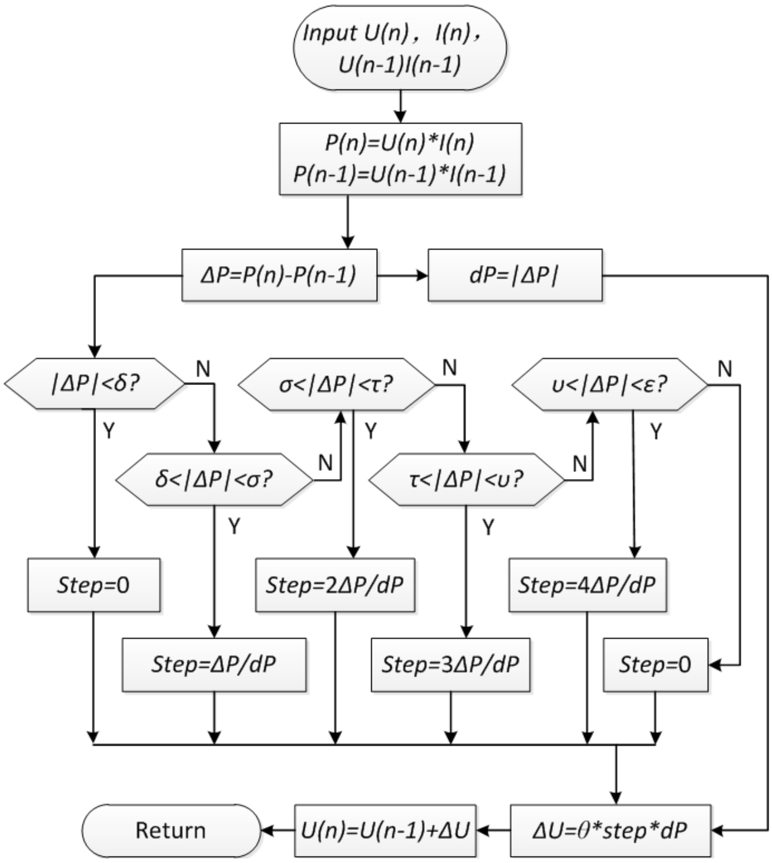


FIGURE 5. Flow chart of the algorithm proposed

4. **Simulation Analysis.**

Using simulink model of PV array in Matlab and combining Boost circuit, the paper builds its MPPT simulation circuit, as shown in Figure 6. The light intensity $R = 1000\text{W/m}^2$, the ambient temperature $T = 25°\text{C}$, the load $R = 30\Omega$, and all the parameters of the simulation device are accordance. The simulation experiments are carried out by using the P&O method and the algorithm proposed in this paper.

4.1. **Starting time.**

Figure 7 respectively shows the P-U curve of the P&O method and the algorithm proposed in this paper when the system runs from start to steady state. It can be seen in this figure, the algorithm proposed in this paper uses 0.04s when the system runs to steady state from start time, but the P&O method uses 0.06s in the same process. The simulation experiments show that the algorithm proposed in this paper is faster than the P&O method in the startup time.

4.2. **Steady-state performance.**

Figure 8 respectively shows the modulation waveform of the algorithm proposed in this paper and the P&O method when the system runs from start to steady state. From the figure known, when the system using the algorithm proposed in the paper reaches to the steady state, the modulation waveform is a straight

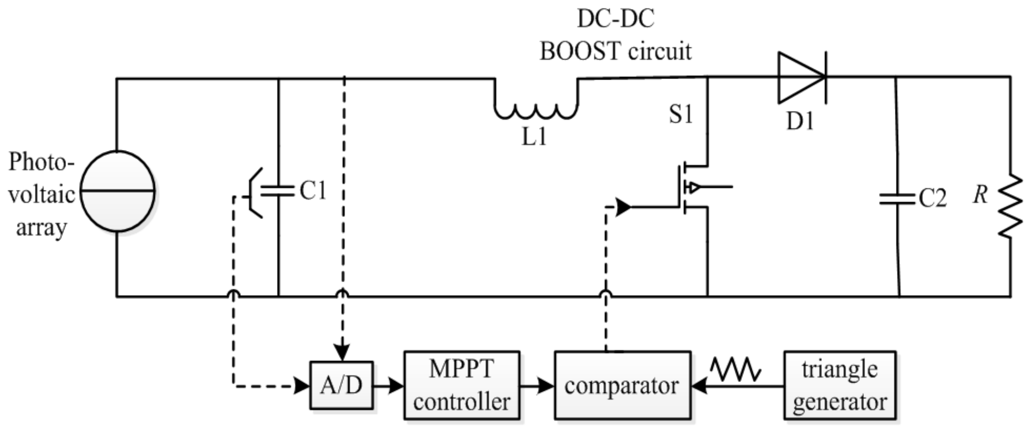


FIGURE 6. Simulation circuit of PV with MPPT control

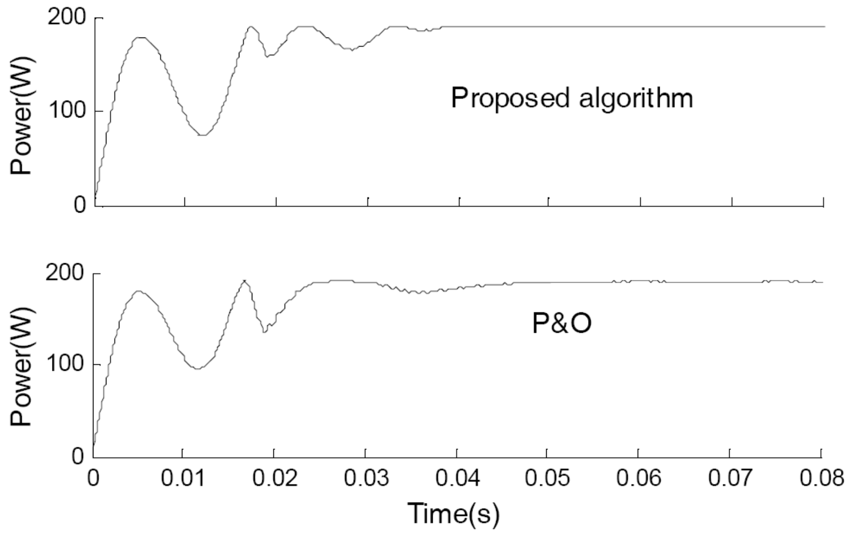


FIGURE 7. P-U curves of the algorithm proposed and P&O on standard conditions

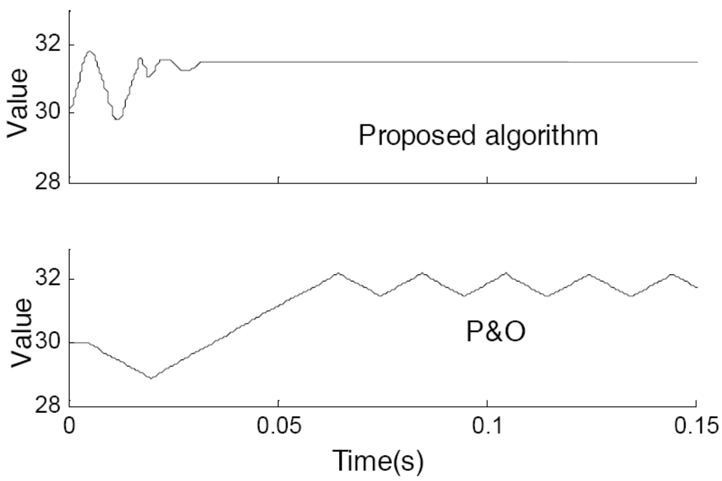
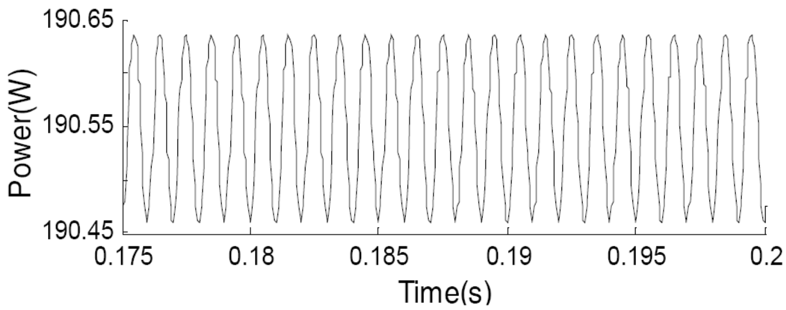


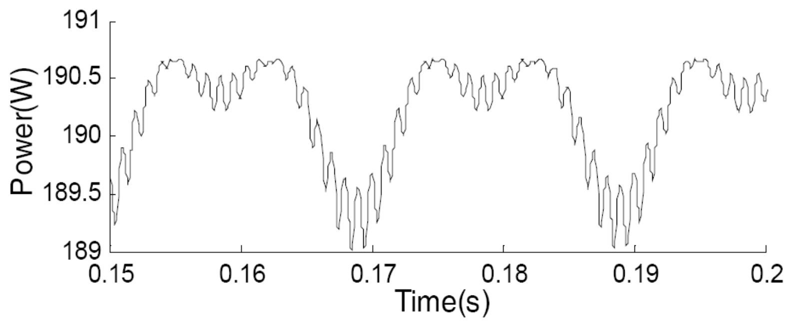
FIGURE 8. Modulation wave curves of the algorithm proposed and P&O on steady state of system

line, but when the system using P&O method reaches to the steady state, the modulation waveform is a sawtooth wave. So when the system is located in steady state, compared with the P&O method, the control signal outputted by the algorithm proposed in this paper is more stable.

In order to facilitate the comparison of the oscillating amplitude between the algorithm proposed in this paper and the P&O method when the system is locked in MPP, now the P-U curves of the system located in steady state are magnified, as shown in Figure 9(a) and Figure 9(b). From Figure 9(a) known, the amplitude of the power oscillation is 0.1W when the system uses the algorithm proposed. From Figure 9(b) known the amplitude of the power oscillation is 0.8W when the system uses P&O method, i.e., the amplitude used P&O method is 8 times than the amplitude used the algorithm proposed in the paper. Those indicate that the algorithm proposed in this paper has the advantage of restraining the system oscillating when the system is located in the steady state compared with P&O method. So the algorithm proposed in this paper can improve the energy conversion efficiency of the PV system and prolong the service life of the power devices.



(a) Algorithm proposed

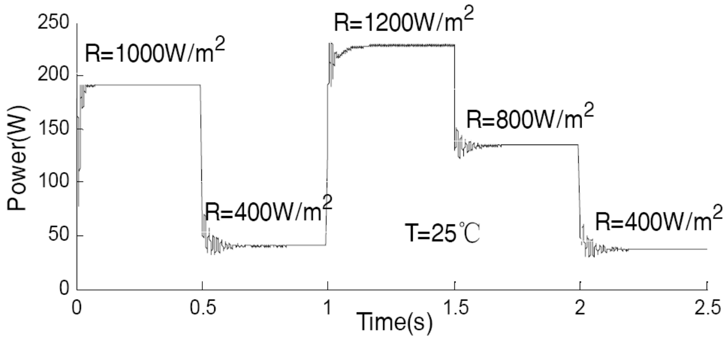


(b) P&O

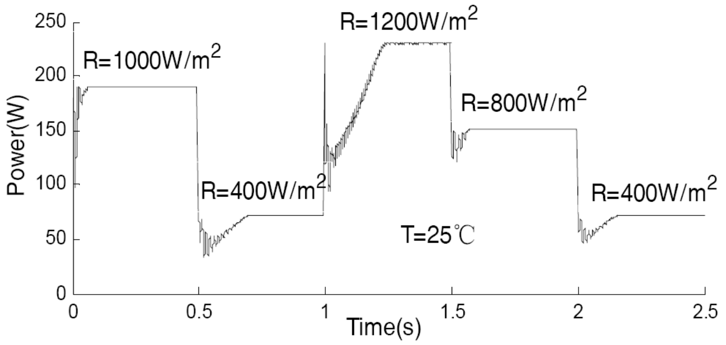
FIGURE 9. P-U enlarged curves of the algorithm proposed and P&O on 0.175s-0.2s

4.3. **Dynamic response.** Figures 10(a) and 10(b) respectively show the P-U curves of the algorithm proposed in this paper and the P&O method when the system is in a situation that the light intensity changes significantly. In Figure 10, all the ambient temperature T = 25°C; when t = 0.5s, the light intensity mutates from 1000W/m^2 to 400W/m^2; when t = 1s, the light intensity is mutated to 1200W/m^2; when t = 1.5s, the light intensity is mutated to 800W/m^2; when t = 2s, the light intensity is mutated to 400W/m^2. From Figures 10(a) and 10(b), it can be known that when t = 1s, the algorithm proposed in this paper quickly traces to the new MPP and is significantly ahead of P&O method.

Figures 11(a) and 11(b) respectively show the P-U curves of the algorithm proposed in this paper and the P&O method when the system is in a situation that the ambient temperature changes significantly. In Figure 11, all the light intensity R = 1000W/m^2;

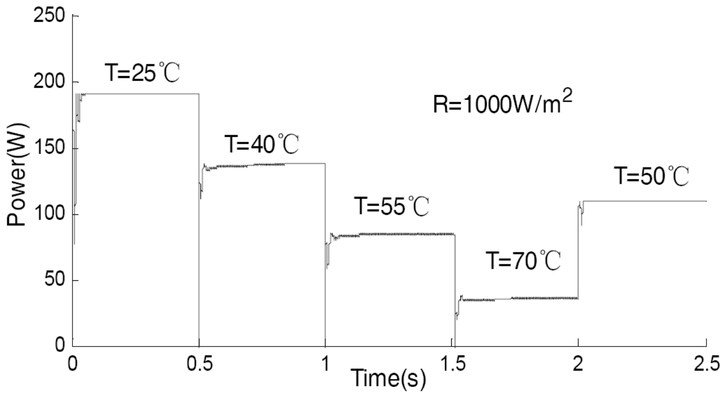


(a) Algorithm proposed

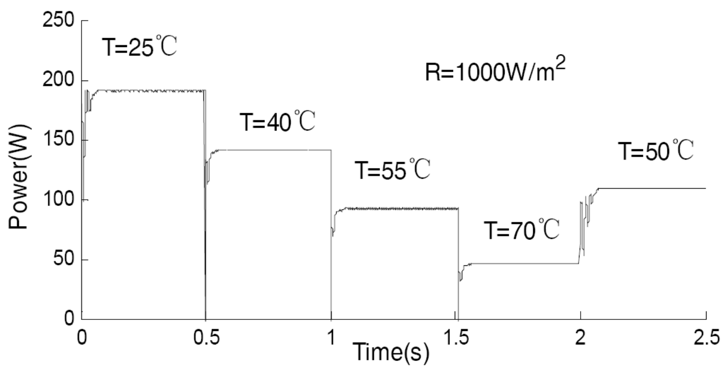


(b) P&O

Figure 10. P-U curves of the algorithm proposed and P&O on the ambient light intensity change sharply



(a) Algorithm proposed



(b) P&O

Figure 11. P-U curves of the algorithm proposed and P&O on the ambient temperature change sharply

when t = 0.5s, the ambient temperature mutates from 25°C to 40°C; when t = 1s, the ambient temperature is mutated to 55°C; when t = 1.5s, the ambient temperature is mutated to 70°C; when t = 2s, the ambient temperature is mutated to 50°C. From Figures 11(a) and 11(b), it can be seen that when t = 2s, the algorithm proposed in this paper quickly traces to the new MPP and is significantly ahead of P&O method.

5. **Conclusions.** Based on the detailed analysis and simulation of the mathematical model and output characteristics of the PV array, a new MPPT algorithm is proposed, which is the partitioned self-adaptive variable step size MPPT algorithm. This paper makes a rigorous theoretical analysis and logical argument for this new MPPT algorithm, and makes a comparison of several data waveforms in the MATLAB/Simulink platform with the P&O method.

The simulation results compared with the P&O method show: the algorithm has the advantages that the step length adaption is well, the amplitude of the P-U curve in steady state is small, and the new MPP can be quickly tracked in the face of significant changes in ambient temperature and light intensity.

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