A new piecewise adaptive step MPPT algorithm for PV systems

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***Abstract*—Maximum power points tracking (MPPT) techniques are widely utilized in photovoltaic (PV) systems to operate at the peak power of PV array which depends on solar and ambient temperature. In this paper, a novel piecewise adaptive step MPPT algorithm is proposed to track MPP by automatically adjusting the step. This algorithm combines the advantages of adaptive step MPPT and partition control MPPT algorithms. It divides the whole tracking zone into several small zones, and uses different adaptive step for each small zone. The MPPT model based on the MATLAB/Simulink platform is established, which takes the duty cycle as the control variable. Simulation results show that the proposed method can largely improve the MPPT response speed and accuracy in both dynamic process and steady state simultaneously.**

Keywords—Photovoltaic (PV) power generation system; maximum power point tracking(MPPT); adaptive step; duty cycle; component.

I. INTRODUCTION

Photovoltaic(PV) generation is becoming increasingly important as a renewable source since it exhibits many merits such as cleanness, little maintenance and no noise. The output power of PV arrays is always changing with weather conditions. Therefore, a maximum power point tracking (MPPT) method becomes indispensable in PV systems. In recent years, several tracking methods have been put forward for tracking the maximum power point (MPP) [1],[2], including constant voltage tracking(CVT), perturbation and observation (P&O) and incremental conductance (INC) methods. The CVT method is based on the parameters of the external environment and its tracking effect is not very ideal. INC method is proposed to improve the tracking accuracy and dynamic performance under rapidly varying conditions [2]. However, null value of the slope of the PV array power versus voltage curve seldom occurs due to the resolution of digital implementation. The P&O method is widely used because of its easy implementation. However, it continues to operate, even at MPP; as a result, the output power may be unstable, thereby decreasing the efficiency of power generation.

Moreover, fuzzy and neural network methods those focus on the nonlinear characteristics of PV array provide a good alternative for the MPPT control. Since the output characteristics of the PV array should be well ascertained to create the control rules, the versatility of these methods is limited [3], [4].

The MPTT algorithm usually uses fixed step. Thus, the design should satisfy the tradeoff between the dynamics and steady state oscillations. To solve the problems, variable step MPPT algorithms have been presented[5-7] with step automatically tuned according to the PV array characteristics. If the operating point is far from MPP, it increases the step which enables a fast tracking ability. If the operating point is near to the MPP, the step becomes very small that the oscillation is well reduced contributing to higher efficiency. Li put forward an adaptive step MPPT algorithm based on power-duty cycle(P-D) characteristic. His algorithm is easy to cause the tracking step to be changed in a large range and lead to tracking of changes, easy to lead to tracking disorder. Chen and Liu presented a partition control MPPT algorithm[6],[7]. Those algorithms may make the system track with small step for a long time and to MPP for too long. This will lead to a greatly reduced dynamic response speed of the system.

To take advantage of the adaptive step MPPT and the partition control MPPT algorithm, a novel piecewise adaptive step MPPT (PAS-MPPT) algorithm is proposed. This algorithm first divides the whole region into several tracking regions, and then adopts different variable step for each tracking region according to the distance between the region and the MPP.

II. PV ARRAY CHARACTERISTICS

Select the boost circuit as the DC-DC transform circuit of the MPPT control circuit for the PV power system. Its topological structure is shown in Fig.1. Where, the PV array is equivalent to the power E. Assume that the voltage at both ends of the load is *U*o. Ii can be expressed as:

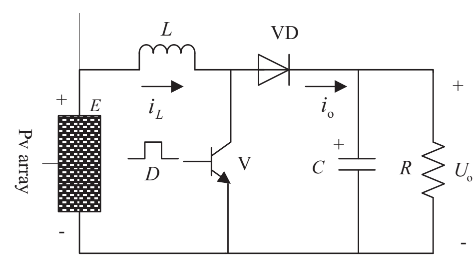


Fig. 1. Topological structure of the boost circuit

$$U_o = \frac{t_{on} + t_{off}}{t_{off}} E = \frac{T}{t_{off}} E = \frac{1}{1-D} E \tag{1}$$

Where, duty cycle $D = t_{on}/T$, and t_{on}, t_{off} represent the time that the controllable switch V in the state of "on" and "off" respectively. *T* represents the switching cycle.

The essence of PV system is to adjust the duty cycle of the boost circuit, so that its internal impedance is equal to the load impedance based on the external environment. Fig.2 shows the impedance transformation process of the Boost circuit.

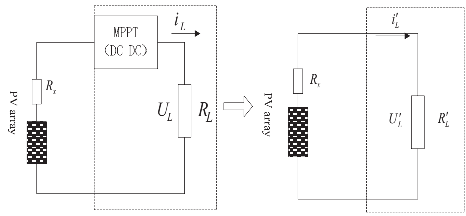


Fig. 2. Impedance transformation process of the Boost circuit

Assuming that the voltages at both ends of the load resistance R_L and R_L' is U_L and U_L' . The currents flowing through the R_L and R_L' are i_L and i_L' . R_L' represents the equivalent load impedance, and R_x represents the internal impedance of the PV array. According to the Eq.(1),we can obtain:

$$U_L = U_L' / (1 - D) \tag{2}$$

Considering that the output power is equal to its input power, we can obtain:

$$i_L = i_L' \times (1 - D) \tag{3}$$

Then:

$$R_L' = \frac{U_L'}{i_L'} = \frac{U_L}{i_L} \times (1-D)^2 = R_L \times (1-D)^2 \tag{4}$$

From Eq.(2), it can be seen that we can change R_L' by adjusting the duty cycle D. When $R_L' = R_x$, the PV array is operated at the MPP position.

III. ADAPTIVE STEP AND PARTITION CONTROL MPPT ALGORITHMS

A. Adaptive step MPPT algorithm

The basic principle of adaptive step MPPT algorithm is: when the working point of the PV array is farther from the MPP, the large step is used to track; when it is close to the MPP, a small step is used. This will not only reduce the power loss near the MPP, but also improve the dynamic tracking performance of the system when the external conditions change dramatically, so as to achieve the desired control effect.

The tracking step is calculated as follows:

$$D(\mathrm{k}+1) = D(\mathrm{k}) \pm N * \left|\frac{\Delta P}{\Delta D}\right|$$

$$\frac{\Delta P}{\Delta D} = \frac{P(k) - P(k-1)}{D(k) - D(k-1)} \tag{5}$$

Where, N is the scaling factor. The step of the duty cycle changes adaptively with the change of $\frac{\Delta P}{\Delta D}$:when it is close to the MPP, a small step is taken, this will assures that the tracking accuracy of the system is higher in the MPP vicinity; correspondingly, when it is far away from the MPP, a large step is taken so as to speed up the tracking speed.

When the working point of the system is far away from the MPP, a fixed large step is taken to enhance tracking speed; when it is close to the MPP, a small step is taken to reduce the power loss and improve the tracking accuracy.

B. Partition control MPPT algorithm

The principle of partition control MPPT algorithm is to set a threshold $\Delta D_{\max} / N$, first, and then divides tracking areas by comparing $\Delta P / \Delta U$ with the threshold:

$$\begin{cases} \left|\frac{\Delta P}{\Delta U}\right| < \frac{\Delta D_{\max}}{N} & \text{close to MPP area} \\ \left|\frac{\Delta P}{\Delta U}\right| \geq \frac{\Delta D_{\max}}{N} & \text{far away from MPP area} \end{cases} \tag{6}$$

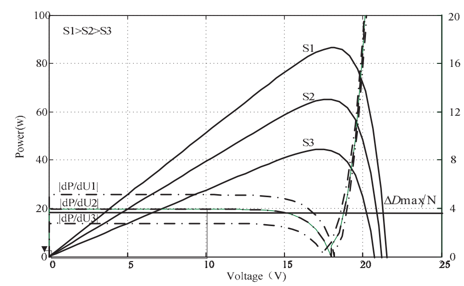


Fig. 3. Schematic diagram of the Partition control MPPT algorithm

This algorithm, by introducing the partition strategy, overcomes the shortcoming of the existing adapt step algorithms which need to through the step ascending process and improves the dynamic performance of the system.

IV. A PIECEWISE ADAPTIVE STEP MPPT ALGORITHM

Based on the above discussion of the adaptive step MPPT and the partition control MPPT algorithms, a novel modified MPPT algorithm named piecewise adaptive step MPPT (PAS-MPPT) algorithm is proposed.

Fig.4 is the schematic diagram of PAS-MPPT algorithm. In the figure, the two curves are the P-D characteristic curve of PV array and the curve of absolute value of the differential of power respectively. It can be seen that when $\Delta P / \Delta D > 0$, the working point of the system is on the left side of the MPP and when $\Delta P / \Delta D < 0$, it is on the right side of the MPP. When the second differential of the power $\Delta^2 P / \Delta D^2 < 0$, it corresponds to the middle lower concave part of the lower part of the absolute value of the differential of power. Let's set a threshold *M*, when $|\Delta P / \Delta D| \leq M$, then the MPP is considered in the area (area A). When $\Delta^2 P / \Delta D^2 < 0$ and $|\Delta P / \Delta D| > M$,the working point of the system is in the areas B,C close to area. When $\Delta^2 P / \Delta D^2 > 0$, the working point of the system is in the areas B,C far away from area A. Based on these, we obtain the conditions for partitioning tracking areas:

$$\begin{cases} \Delta^2 P / \Delta D^2 < 0 \\ \left| \Delta P / \Delta D \right| \le M \end{cases} \tag{7}$$

This algorithm can make full use of both the adaptive step MPPT and the partition control MPPT algorithms. The tracking step of each area of the improved algorithm is:

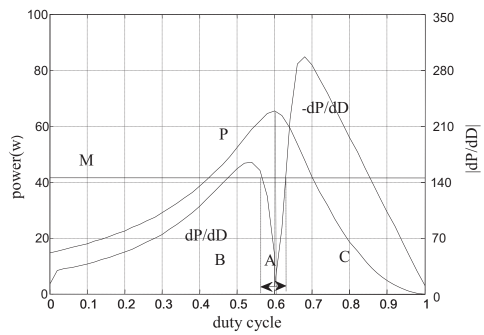


Fig. 4. Schematic diagram of PAS-MPPT algorithm

$$D(k) = \begin{cases} D(k-1) \pm \Delta D_{\max} & \text{B,C areas and far away from A area} \\ D(k-1) \pm \Delta D_0 & \text{B,C areas and close to A area} \\ D(k-1) \pm \lambda & \text{A area} \end{cases} \tag{8}$$

$$\lambda = e^{-\left|\frac{\Delta^2 P}{\Delta D^2}\right|} (1 - 1 / (\left|\frac{\Delta p}{\Delta D}\right| + 1)) \tag{9}$$

where $\Delta D\text{max}$ is a fixed big step, ΔD_0 is a fixed small step.

Based on Eq.(8) we can see, if the working point is in area B or C and far away from A, maximum step $\Delta D\text{max}$ is taken for fast approaching. If the working point is in area B or C and close to A, a relatively small step ΔD_0 is taken for quickly entering A, to prevent the step to be too large to enter A and fluctuate in B and C. If the working point is in area A, the step is calculated using Eq.(9),which adaptively changes the step based on the $\left|\frac{\Delta P}{\Delta D}\right|$ and $e^{-\left|\frac{\Delta^2 P}{\Delta D^2}\right|}$. A relatively high tracking accuracy can be obtained using the adaptive small step in area A.

Fig.5 is the flow chart of the PAS-MPPT algorithm presented here. This algorithm, not only overcomes the shortcoming of the existing adapt step algorithms which need to through the step ascending process and improves the dynamic performance of the system. But also avoids the tracking step jump phenomenon caused by the mutation of the external environment. This algorithm, by adaptively changing tracking step, overcomes the shortcomings of the partition control MPPT algorithm which may track the MPP for a long time by taking small step and make the system to track the MPP time be too long, and the dynamic response speed of the system be greatly reduced.

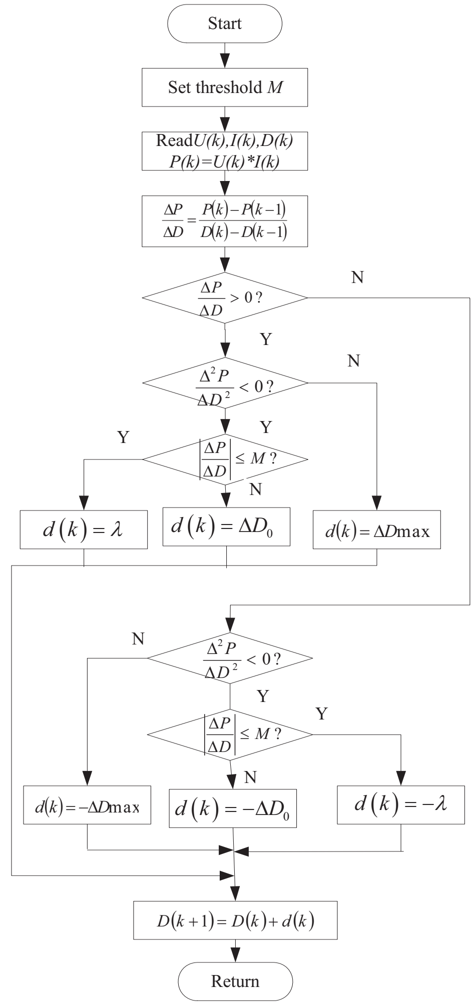


Fig. 5. Flow chart of the PAS-MPPT algorithm

V. Simulation Results

A. Simulation Model

In this paper, the MPPT model of PV system is built in the Matlab/Simulink environment, where the DC-DC transform circuit in the control circuit is expressed as the boost module. Its internal structure is shown in Fig.5 and the solar panel module is the PV arr**ay simulation m**odel. What embedded in the S-Function module is specific algorithm written with S functions. The improved PAS-MTTP algorithm is realized by S function written by C language.

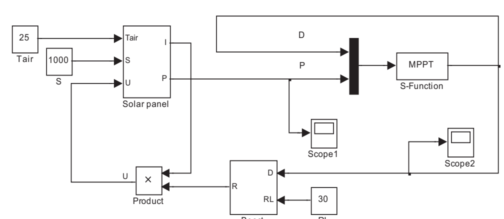
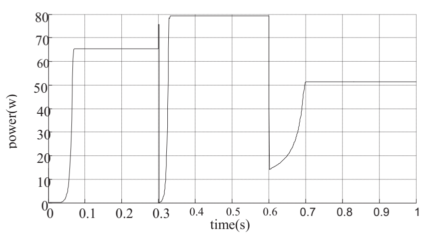


Fig. 6. Simulation Model of the PAS-MPPT algorithm

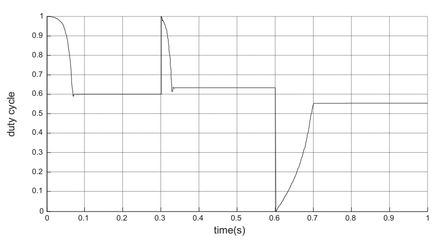
B. Comparison of simulation results

In order to compare the tracking performances of the PAS-MPPT algorithm with the adaptive step MPPT and partition control MPPT algorithms, simulation experiments have been carried out respectively. The initial conditions are set as: S=1000W/m^2,T_{air}=25℃, the simulation time is 1s. The light intensity becomes 1400W/m^2 at t=0.3s and 800W/m^2 at t=0.6s.

By comparing the power responses in Fig.7, Fig.8 and Fig.9, we can see that the three algorithms can all track the MPP quickly at the initial stage. From Fig.7, it can be seen that the tracking step needs to be change to large first and then decreased by adopting the adaptive step MPPT algorithm. When the light intensity is reduced from 1400W/m^2 to 800W/m^2, the tracking time required for the new MPP exceeds 0.1s. From Fig.8 it can be seen that when the light intensity is reduced from 1400W/m^2 to 800W/m^2, due to the partition policy failure, the system will track for a long time by taking small step, the tracking time required for the new MPP exceeds 0.1s and is slightly longer than the other two algorithms. From Fig.9, it can be seen that when the environment changes, whether the light intensity enhance or weaken, the tracking time to the new MPP is less than 0.04s.

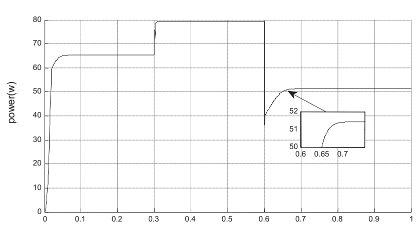


(a) power response

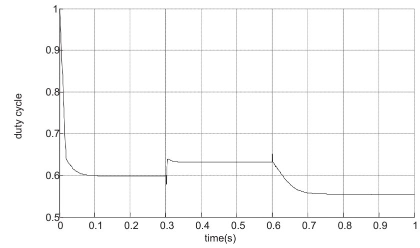


(b) duty cycle response

Fig. 7. Simulation results of Adaptive step MPPT algorithm

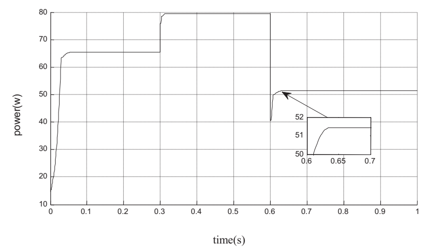


(a) power response

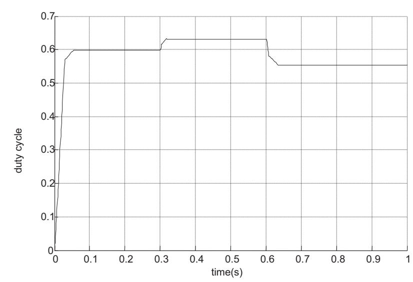


(b) duty cycle response

Fig. 8. Simulation results of partition control MPPT algorithm



(a) power response



(b) duty cycle response

Fig. 9. Simulation results of PAS-MPPT algorithm

Compared with the other two algorithms, the PAS-MPPT algorithm effectively improves the tracking speed of the system. By introducing the partition control strategy, the problem of tracking step jump is effectively solved. By using different variable step algorithm in each tracking region, the long time use of small step of the partition control MPPT algorithm is avoided, this makes the system take into account both steady state and dynamic characteristic.

VI. CONCLUTION

In this paper, a modified MPPT algorithm named piecewise adaptive step MPPT algorithm is proposed based on the adaptive step MPPT and the partition control MPPT algorithms. It can take advantages of both algorithms and improve the dynamic and steady state performance of the PV system simultaneously by introducing partitioning strategy into the adaptive step MPPT algorithm. Comparison simulation experiment of the adaptive step MPPT, the partition control MPPT and PAS-MPPT algorithms are carried out with MATLAB/SIMULINK and the results verify the feasibility and effectiveness of the proposed algorithm.

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