An Improved Variable Step Size P&O MPPT Algorithm Based on Constant Voltage and K Division Technology

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Abstract. In the literature, various techniques have been proposed to achieve the maximum output power of photovoltaic cells, but the fixed step size perturbation and observation and incremental conductance algorithm can’t enhance effectively the peculiarity of the PV system, due to their slow tracking speed, big power loss and limited accuracy. An improved variable step size perturbation and observation MPPT algorithm based on the K division method is proposed. The symbol of $\frac{dp}{du}$ before and after the disturbance is judged, if the two adjacent samples have the same symbol, the disturbance step size remains unchanged. On the contrary, the disturbance step size will be divided by K and become the new disturbance step size until achieving the maximum output power. The simulation establish on MATLAB/Simulink reveals that the method has fast response speed, high accuracy, low power loss, and can locate the new maximum power point quickly when environmental conditions change.

1. Introduction

As the the rapid consumption of fossil resources, energy and environmental issues are particularly prominent. People began to replace traditional fossil energy\textsuperscript{[1]} with renewable energy. Photovoltaic power are in a more significant position in renewable energy. For the sake of maximize the output power of photovoltaic system (PV system), which is called Maximum Power Point (MPP), Maximum Power Point Tracking (MPPT) technology is needed. Currently, there are numerous MPPT algorithms\textsuperscript{[2-3]}, including constant voltage method (CVT), perturbation and observation method (P&O), incremental conductance algorithm (INC), fuzzy logic method and neural network algorithm and so on. CVT determines the voltage at the MPP quickly in terms of magnitude of open-circuit voltage, this is easy to be implemented, but it can’t automatically track the MPP while the temperature and light intensity change\textsuperscript{[4]}. The fixed step size P&O method detects the output power by giving a small disturbance to the output voltage, while the speed and accuracy can’t be achieved simultaneously\textsuperscript{[5]}. INC is in the light of differential results of the output power on voltage, the regulation effect is affected seriously by the step size\textsuperscript{[6]}.

An improved K divided step size P&O algorithm (K-P&O) is proposed, which starts at constant voltage and then judge the $\frac{dp}{du}$ symbols before and after the perturbation. The step size depends on the symbols’ variation until the output remains constant finally.

2. K division based improved variable step size MPPT algorithm

The equivalent circuit diagram\textsuperscript{[7-8]} of the PV cell is displayed at figure 1.
Figure 1. PV cell equivalent circuit.

The output properties of photovoltaic cells can be signified as:

\[
I = I_{ph} - I_d[\exp(V + IR_{sh})/nKTN_s/q) - 1] - \frac{V + IR}{R_{sh}}
\] (1)

where \(I_d\) is reverse saturation leakage current of PV cells; \(n\) is the diode ideal factor \((1 \leq n \leq 2)\); \(q\) is the amount of charge contained in a single electron; \(k\) is Boltzmann constant; \(N_s\) represents the quantity of photovoltaic cells in series; \(T\) on behalf of the temperature \((^\circ F)\).

When \(S_{ref}=1000\text{W/m}^2, T_{ref}=25\text{\degree C}\), equation (1) can be simplified to obtain the output characteristics of photovoltaic cells[9-10].

\[
\begin{align*}
I &= I_s[1 - C_1(e^{U_{oc}/U_{sc}} - 1)] \\
C_1 &= (1 - \frac{I_m}{I_s})e^{U_m/U_{sc}} \\
C_2 &= \frac{U_m}{U_{oc}} - 1) / \ln(1 - \frac{I_m}{I_s})
\end{align*}
\] (2)

When the working condition of photovoltaic modules changes, the \(I_{oc}, U_{oc}, I_m, U_m\) can be modified as follows:

\[
\begin{align*}
I'_{sc} &= I_s (1 + AS)(1 + a\Delta T) \\
U'_{oc} &= U_{oc} \ln(e + bAS)(1 - c\Delta T) \\
I'_{m} &= \frac{U_m}{U_{oc}} (1 + AS)(1 + a\Delta T)
\end{align*}
\] (3)

Where \(a\) is the current temperature coefficient, which is 0.0025; \(b\) is 0.55; \(c\) is the voltage temperature coefficient, which is 0.00285; \(e\) is the base of natural logarithms; \(\Delta S=S_{ref}-S\); \(\Delta T=T-T_{ref}\).

The PV cell model is establish on Matlab/Simulink, then simulation parameters are set as follows: \(U_{oc}=22.2\text{V}, I_{oc}=8.58\text{A}, U_m=17.7\text{V}, I_m=7.94\text{A}\). The characteristics of P-U curves under different conditions as shown in Figure 2. It shows that the light intensity is the main factor affecting the output specific properties of PV cells.

Figure 2. Output properties of PV cell in diverse environments.  
(a) S=1000W/m$^2$, P-U properties under three temperatures  
(b) T=25\degree C, P-U properties under three light intensities  

Towards the traditional fixed step size P&O method has slow speed and short precision, an K-P&O
algorithm is put forward, as is based on constant voltage (about 0.76U_{oc}) startup and variable step size P&O method, it can be seen in figure 3:

![Figure 3. The output P-U performance curve and | dp/du | performance curve of PV Cell.](image)

Figure 3 shows that on the left side of the MPP, dp/du>0; at the MPP, dp/du=0; on the right dp/du < 0. The step size can be changed by judging the symbols of dP_n/dU_{n+1} and dP_n/dU_n before and after the perturbation. The details are as follows:

In the wake of the rise of light intensity, the short circuit current I_{sc} rises significantly while the open circuit voltage U_{oc} increases mildly[2]. Under the condition of constant light intensity, starting with a constant voltage and a large disturbance step ΔU (set to A), then judging the symbols of dP_n/dU_{n+1} and dP_n/dU_n. If the voltage before and after disturbance is less than the MPP voltage, (dP_n/dU_{n+1})>(dP_n/dU_n)>0, dP_n/dU_n<0, then the step size remains unchanged and the disturbance direction is to increase the output voltage and if greater than the MPP voltage, (dP_n/dU_{n+1})>(dP_n/dU_n)<0, dP_n/dU_n<0, then the step size remains unchanged and the disturbance direction is to reduce the output voltage. If the voltage before and after disturbance are located on both sides of the MPP voltage, (dP_n/dU_{n+1})<(dP_n/dU_n)<0, then dividing the perturbation step size by K (K is greater 1) and judging the symbol of dP_n/dU_n, if dP_n/dU_n > 0, the direction of disturbance is to reduce the output voltage, if dP_n/dU_n < 0, the direction of disturbance is to enhance the voltage. The perturbation is repeated until the output voltage of the photovoltaic cell meets | U_{n+1} - U_n |<α (take α = 0.1 here), U_{ref} = U_{ref}. The step size change rule is shown in equation (4).

\[
\Delta U = \begin{cases} 
\frac{\Delta U}{K} (dP_{n+1}/dU_{n+1}) \times (dP_n/dU_n) < 0 \\
\Delta U, (dP_{n+1}/dU_{n+1}) \times (dP_n/dU_n) > 0 
\end{cases}
\] (4)

When the light intensity changes abruptly, so does the output current. If | I_{n+1} - I_n |>β, it shows the light intensity changes abruptly, and the step size ΔU should be re-assigned (set to B), the photovoltaic cells start with a larger step size. Otherwise, if | I_{n+1} - I_n |<β, the step size remains unchanged. The flow diagram is expressed in figure 4.

![Figure 4. An improved K-P&O MPPT method.](image)

3. Simulation and analysis
The artificial circuit is set up on the platform of Matlab/Simulink, as shown in figure 5. DC/DC converter uses boost circuit. Taking α = 0.1, β = 1, L=10mH, C1=100uF, C2=300uF, R=30Ω, starting voltage is 0.76 U_{oc}. When the light intensity changes, the step size is re-assigned as B=0.01.
I: When $S=1000\text{W/m}^2$ and $T=25\, ^\circ\text{C}$, $K = 1.5, 2, 2.5, 3$ is taken in turn, and the result is compared with the traditional fixed step size P&O and INC. When $K = 1.5, 2$ and 2.5, the initial disturbance step size is $A = 0.1$. The simulation results are shown in figure 6. Response time and power loss are shown in Table 1.

**Table 1.** System response time and power loss

|                | P&O | INC | K-P&O K=1.5 | K-P&O K=2 | K-P&O K=2.5 |
|----------------|-----|-----|-------------|-----------|-------------|
| Response time (s) | 0.025 | 0.024 | 0.038 | 0.01 | 0.00965 |
| Power loss (W)    | 4.85  | 4.5  | 0.25 | 0.18 | 0.055 |

When $K=3$ and $A=0.1$, the $K$ divided step size reduced too much and then it leads closing slowly to the MPP in the opposite direction with the long response time. Reduce $A$ to 0.025, the response time becomes smaller and the output power has only slight oscillates in the early response, as shown in figure 7. However, a too small $K$ leads much the output power oscillation loss. A desired $K$ is within a reasonable range. Figure 8 shows the output characteristic curve with $K = 1.5, 1.7, 2, 2.5, 2.7$ and 2.8. System response time and power loss at different $K$ values in Table 2 show that the optimal value range of $K$ is $(1.8, 2.7)$ when $A = 0.1$. 

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**Figure 5.** Photovoltaic cell simulation model.

**Figure 6.** Simulation results when $K=1.5, 2$ and 2.5.

**Figure 7.** Simulation results when $K=3$. 

**Figure 8.** Simulation results when $K=3$. 

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1. When $S=1000\text{W/m}^2$ and $T=25\, ^\circ\text{C}$, $K = 1.5, 2, 2.5, 3$ is taken in turn, and the result is compared with the traditional fixed step size P&O and INC.
Figure 8. Simulation results with different values of K.

| K   | Response time (s) | Power loss (W) |
|-----|------------------|----------------|
| 1.5 | 0.038            | 0.25           |
| 1.7 | 0.025            | 0.32           |
| 2   | 0.01             | 0.18           |
| 2.5 | 0.00965          | 0.055          |
| 2.7 | 0.00968          | 0.65           |
| 2.8 | 0.25             | 1.8            |

Table 2. System response time and power loss at different K values

II: the light intensity varies from 1000 W/m² to 800 W/m² and then 600 W/m², the temperature varies from 25°C to 37°C and then 45°C, respectively, setting A=0.1, K=1.9 and B=0.01, the simulation output can be seen in figure 9 and 10 respectively.

Curves show that the proposed K-P&O algorithm quickly tracks the new maximum power point with smaller power loss than the traditional P&O and INC algorithm when S changes abruptly.

4. Conclusion
Based on constant voltage method and the K division technology, an improved MPPT strategy of variable step size P&O algorithm is put forward. In early response period a large scale disturbance is used and step size gradually reduces by K-divided to approach the MPP quickly, moreover K is not limited to a fixed value. The simulation on Matlab/Simulink platform shows the modified algorithm has better response speed, smaller power loss and higher precision than the P&O and INC method. In the cases of the light intensity and temperature change abruptly, this algorithm also can accurately track the MPP, which is very useful in the practice.

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