TRACKING THE MAXIMUM POWER POINT OF PV ARRAY USING DICHOTOMOUS SEARCH

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The overall efficiency of a photovoltaic (PV) system relies very much on the conversion efficiency and the environmental conditions. The conversion efficiency of typical Silicon based PV array is relatively low. The irradiation and climatic conditions influence the PV array current significantly and this in turn affect the maximum power that can be generated by the PV array. Therefore, it is essential to operate the PV array at its optimal operating point to ensure better harvest efficiency. Many algorithms have been proposed in literature to track the maximum power point. This paper proposes dichotomous search-based tracking algorithm to identify the optimal operating point of PV array under homogeneous irradiation conditions. This algorithm is based on "divide and discard" strategy and hence the convergence speed is relatively better than the conventional hill climbing algorithms. The reliability of the algorithm is tested for various homogeneous irradiation conditions on a 3×3 array and the simulated results are presented.

Keywords: photovoltaic array; homogeneous irradiation; MPPT; dichotomous search

1. Introduction

Power generation by renewable systems is gaining recognition these days due to the general awareness and concern about the adverse impacts of the pollutants released by the combustion of non-renewable fossil fuels. The affordability, scalability, decentralized operation and the ability to operate in stand-alone mode have made the solar PV based power generation a feasible and favorable option among the other renewable sources. A typical PV based energy conversion system includes PV generator to convert Sun's light energy to electrical energy and power conditioning unit (PCU) to process the generated power. The overall efficiency of the system relies very much on the efficiency of the PV generator. The conversion efficiency of the PV cell relies on the material and it is around 14% for conventional Si based PV cells. Besides, the power generated by the PV cell is reliant on irradiation and temperature. The photo current and the power generated by the PV cell decrease with irradiation and the

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variation are manifested in its electrical characteristics. Both the voltage-current (VI) and the voltage-power (VP) characteristic of a PV cell are non-linear and the VP curve exhibits a maximum called the maximum or peak power (PP) [1-2]. The low conversion efficiency and the environmental dependence enforce the operation of the PV cell at its optimal point. However, the PP of a PV cell is not constant but varies with the environmental conditions [3-4]. This necessitates the need of a tracking algorithm that can identify the optimal power point under all homogeneous irradiation conditions.

Another major challenge pertaining to the building applied PV system is partial shading. In case of smaller installations that are deployed on the rooftop, utmost care is taken in the planning stage itself and the panels are installed in such a way that they are free from the shadings that are cast by the nearby structures. Even if the panels are shaded by clouds, the shading will be homogeneous considering the size of the array. In such circumstances, the VP characteristics will exhibit single maximum and conventional MPPT algorithms work well.

The widely adopted tracking techniques include fractional voltage, fractional current and hill climbing algorithms. The voltage-based algorithm called the fractional voltage is based on the study which states that the ratio of the voltages at array's PP and open circuit condition is almost constant ('k'). In case of the current based algorithm, current at array's PP and the short circuit currents are considered to calculate 'k'. Though these algorithms are simple, reliance of 'k' on temperature and irradiation and separation of PV array for measurement, results in lower efficiency. In the algorithms formulated on hill climbing principle, the array voltage is perturbed, and the corresponding power is measured. Perturbation is continued in the direction where there is an increase in power. The AI based algorithms are efficient, but the accuracy depends on the rule base and data set used for training. Many such tracking algorithms are reported in literature with varied complexity, speed and accuracy [5-12].

This paper proposes a new algorithm based on dichotomous search to effectively track the peak power under all homogeneous irradiation conditions. This numerical search algorithm is rather fast as it is based on 'divide and discard' technique. The search interval is almost reduced to half at the end of each of the iterations and this enhances the speed of tracking. The algorithm and its pseudo code are presented in the following section. The proposed algorithm called the dichotomous search maximum power point tracking (DS MPPT) algorithm is validated for a 3×3 array through Matlab based simulations.

2. The system description

Maximum power is drawn from the PV array if the load impedance is matched with that of the source impedance. The source impedance (PV) however varies with environmental conditions. The irradiation intercepted by the panels will be the maximum if the sky is clear. Due to the dynamic weather conditions, the irradiation may not be constant. As a result, the source impedance varies and, therefore, to match the impedances, a dc-dc converter is placed amid the source and the load. The widely used converters are buck, boost or Cuk converter. The diagrammatic representation of the PV system with MPPT is presented in Fig. 1.

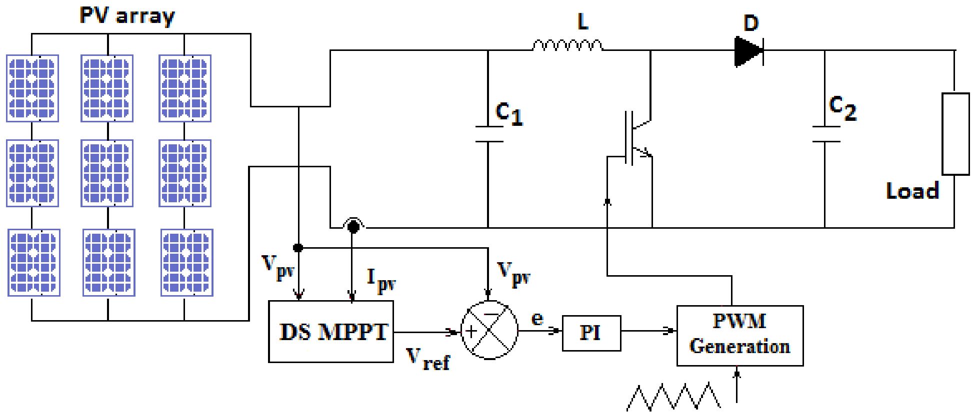

Fig. 1. PV system with MPPT

The PV panel considered in this work has a peak power of 37 W and the system parameters including the specifications of the 3×3 PV array are given in Table 1.

Table 1

Parameter specifications

Converter specification		PV Specification	
Parameters	Specification	Electrical parameters	PV Array
L	2.8 mH	Open circuit Voltage V_{oc}	63.72 V
C_1	29 μF	Short circuit Current I_{sc}	7.65 A
C_2	2500 μF	Maximum Power P_{pp}	335.3 W
Switching frequency	10 kHz	Voltage at maximum power V_{pp}	50.7 V
Switch	IGBT	Current maximum power I_{pp}	6.6 A

The dc-dc converter is a boost converter operating in continuous conduction mode. The array voltage and current are sensed, and the proposed DS algorithm generates the reference voltage while the PI controller controls the array voltage by altering the width of the pulses given to the switch. The PV array is to be analyzed for different irradiation conditions to fix the initial search interval for the algorithm to track.

A 3×3 PV array connected in series-parallel connection is considered in this work. Each of the PV panel has 36 serially connected poly crystalline PV cells and single bypass diode. The array is modeled in MatLab and the electrical characteristics are simulated for different irradiation conditions. The simulated VP characteristics of the array are depicted in Fig. 2 as the irradiation is varied from 200 W/m^2 to 1000 W/m^2 in steps of 100 W/m^2.

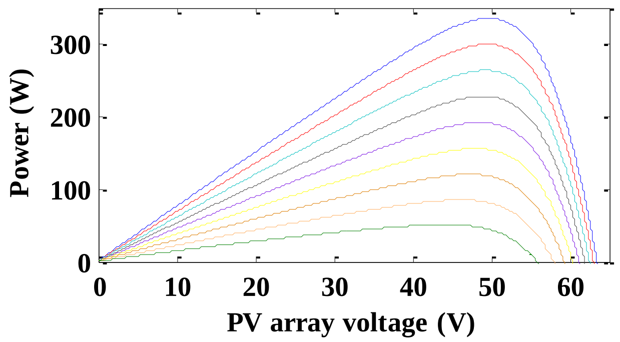

Fig. 2. VP characteristics of array under various irradiation levels

The characteristic curves exhibit unique peak as homogeneous irradiation conditions is assumed in this work. It is evident that the peak power reduces significantly with the irradiation (from 335.3 W at 1000 W/m^2 to 50.73 W at 200 W/m^2). The voltage at which the peak power occurs is denoted by 'V_{pp}'. Generally, V_{pp} for a panel is approximately 'k' times its open circuit voltage and, studies show that the range of 'k' lies between 70 - 85% depending on the environmental conditions. The variation in the V_{pp} for the considered 3×3 array with respect to the irradiation is depicted in Fig. 3.

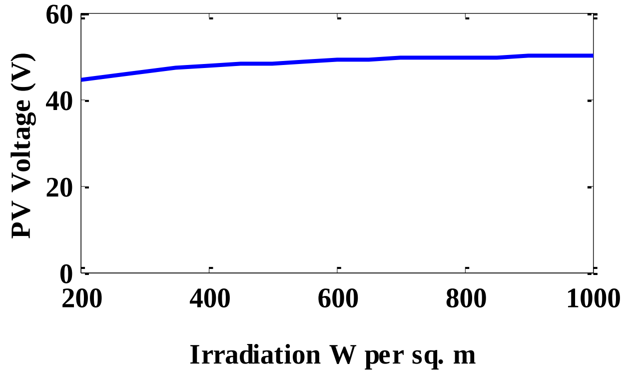

Fig. 3. Change in V_{pp} with irradiation

The voltage (V_{pp}) varies from 49.72 V to 44.46 V as the irradiation changes from 1000 W/m^2 to 200 W/m^2. Though the variation in V_{pp} with respect to irradiation is smaller, the variation in power is significant (335.3 W to 50.73 W) and this demonstrates the importance of tracking the PP.

3. The proposed DS MPPT algorithm

The proposed algorithm is a single stage algorithm where the entire voltage range is swept to identify the peak power. The voltage range to be swept depends on the size of the array and the way the panels are configured within. For an m × n array connected in series-parallel configuration ('m' panels in series and 'n' strings in parallel), the voltage range extends from 0 to 'm' times the open circuit voltage of a panel. To speed up the process, the search interval is to be reduced and only significant region is searched for peak. As the V_{pp} tends to lie between 70 % and 85 % of arrays' open circuit voltage, the search interval is fixed around it. The interval to be searched for peak in an m×n array is fixed as $0.65mV_{oc\_panel}$ to $0.85mV_{oc\_panel}$. For the 3×3 array considered in this work, the search interval is fixed as (41, 54) V. The DS algorithm will search this interval using 'divide and discard' technique to identify the exact location of the peak. The algorithm and its pseudo code are presented below.

The DS algorithm locates the maximum or peak of a unimodal function (function with single peak) in the given interval (a, b) by repeated division and elimination. The centre point 'c' (c = (a+b)/2) of the interval is computed and two search points $x_1 = c - \varepsilon$ and $x_2 = c + \varepsilon$ are fixed on either side of the midpoint. This results in two sections (a, x_2) and (x_1, b) as shown in Fig. 4. Value of ε is chosen to be a very small value for accurate tracking. One of the sections is discarded at the end of the iteration and the search continues with the remaining one. To eliminate the section, the function is assessed at the two search points x_1 and x_2.

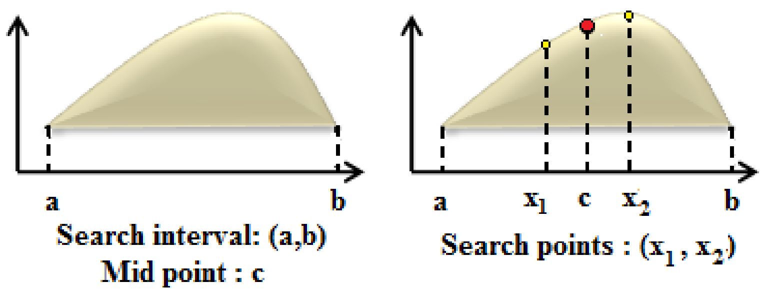

Fig. 4. Search interval of DS algorithm

If $f(x_2) > f(x_1)$, the section (a, x_1) is eliminated as the section does not include maximum. If $f(x_1) > f(x_2)$, section (x_2, b) is eliminated as the section does not include maximum. Thus, a section is eliminated at the end of each of the iteration and new search points are introduced for further iterations. The progress in tracking as the algorithm searches and narrow down the search interval is depicted pictorially in Fig. 5.

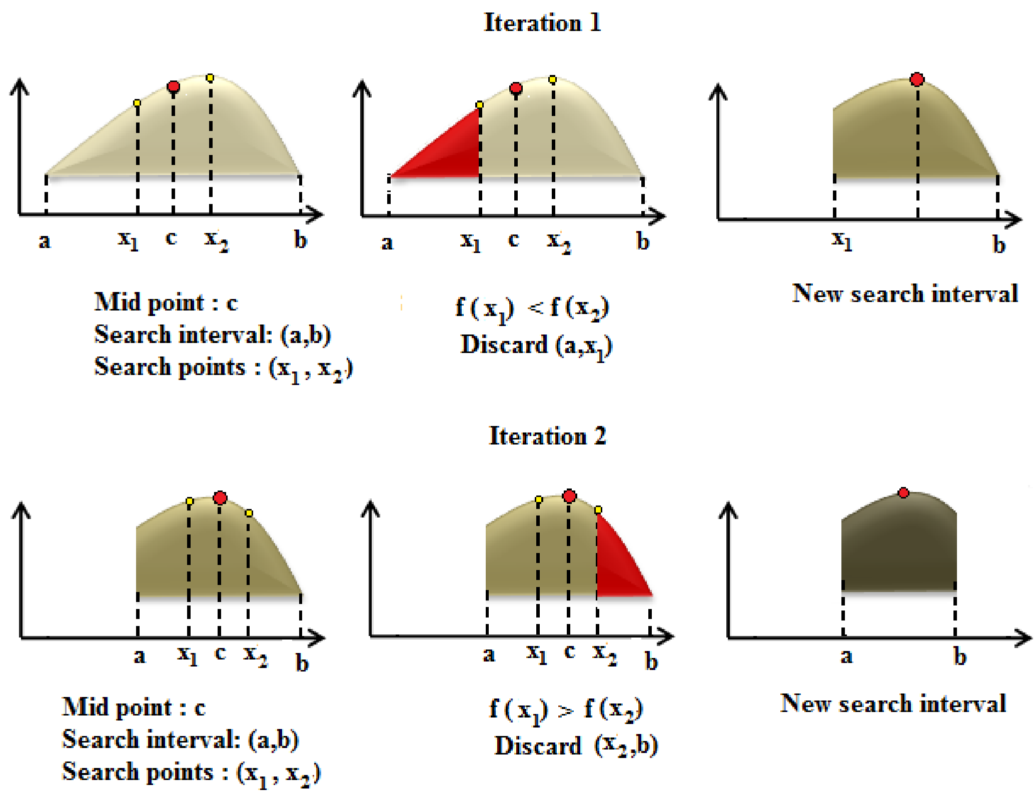

Fig. 5. Reduction of search interval in DS algorithm

The initial interval is (a, b) and the centre point is marked as c. On assessing the function at the two search points x_1 and x_2, it is found that $f(x_2) > f(x_1)$. This indicates that the peak does not lie in the section (a, x_1) and hence it is discarded. The first iteration has thus reduced the search interval to (x_1, b). The centre point and probe points are fixed, and the function is assessed at the new search points. The iteration is continued until the search interval shrinks to the peak point ($a - b < \Delta$, where, Δ is a very small value). The algorithm is summarized, and the pseudo code is given below. The flow chart of the proposed algorithm is presented in Fig. 6 and it includes the main function and the subroutine. The main function looks for change in irradiation and the subroutine fixes the search interval and locates the peak point by Dichotomous search technique. The reduction in search interval as the algorithm progresses is presented in Fig. 5. Flags indicate the completion of the stages.

Algorithm

Step 1: *Measure power, if deviation in two successive measurements is significant, initiate search*

Step 2: *Fix the search interval (a, b)*

Step 3: *Fix the probe points x_1 , x_2 and centre point c*
Step 4: *Measure the power P_1 and P_2 at the probe points*
Step 5: *If $P_1 > P_2$, shift left; if $P_1 < P_2$, shift right*
Step 6: *Fix new search interval*
Step 7: *Repeat steps 3-5 till maximum power point is identified*

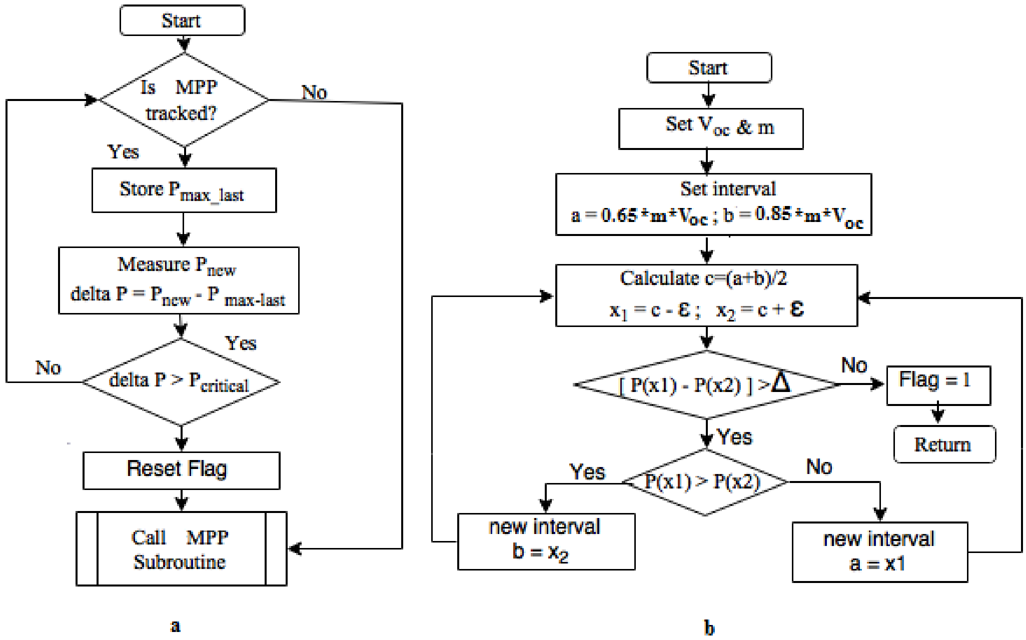

Fig. 6. Flowchart of proposed algorithm: (a). Detection of change in irradiation (b). MPP subroutine

The algorithm searches for the peak and after locating, it terminates the search by setting the flag to 1. The reference voltage remains unaltered until the irradiation conditions changes. The algorithm senses changes of this sort by calculating the deviation in peak power (ΔP) periodically as shown in Fig. 6. a. If there is any variation in the environmental conditions, the deviation is large. Smaller deviation can however be neglected. If $\Delta P > P_{critical}$, new search is initiated, and the main program calls the MPP subroutine given in Fig. 6. b to rescanning the entire range and track the new peak through series of iterations.

4. Results and discussions

The tracking capability of the proposed DS MPPT algorithm is examined at standard irradiation condition and changing irradiation/shading (homogeneous) conditions. The 3×3 array considered in this work generates a maximum power of 335.3 W at standard irradiation (1000 W/m^2). The peak occurs at 49.72 V and it is effectively tracked by the proposed DS MPPT algorithm. The reference voltages generated by the algorithm and the actual PV array voltage are depicted in Fig. 7.

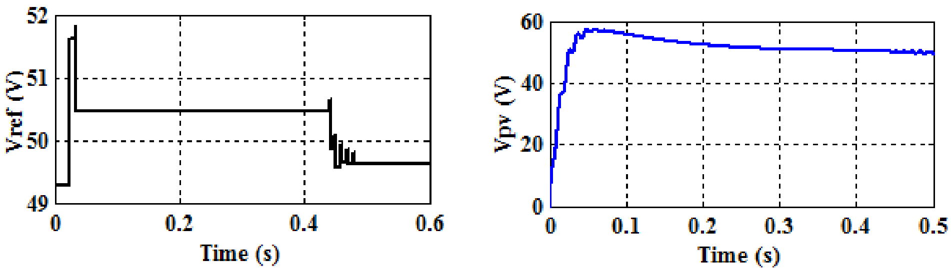

Fig. 7. (a). Reference voltage generated by DS MPPT (b). PV array voltage

The algorithm is reliable only if it can detect the change in irradiation conditions and track the peak power point appropriately. The reliability of the proposed DS MPPT algorithm is tested by dynamically changing the irradiation/shading levels. The irradiation level of the 3×3 array is changed from 1000 W/m^2 to 500 W/m^2 and then to 355 W/m^2 and finally to 900 W/m^2. The reference voltage generated by the algorithm for this dynamic case is presented in Fig. 8. The irradiation levels are also shown in the figure.

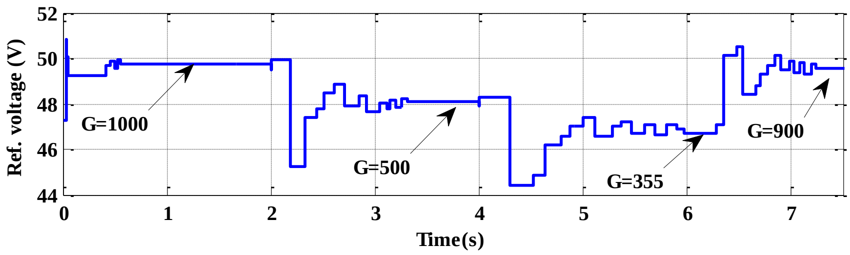

Fig. 8. Reference voltage generated by DS MPPT for dynamic shading

The proposed algorithm generates the reference voltage and the controller operates the PV array at that voltage. As the algorithm progress, the search interval is tapered down and the peak point is detected by the algorithm. The PV voltage is presented in Fig. 9.

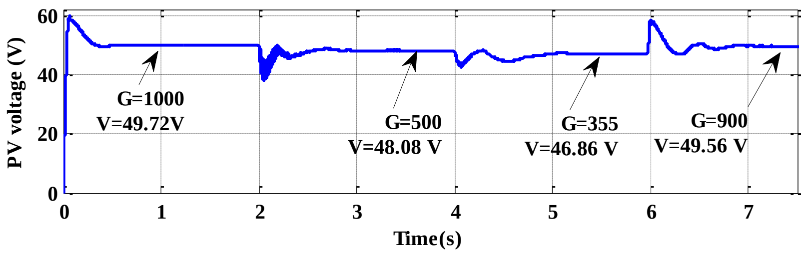

Fig. 9. Variation in PV voltage

It is evident from Fig. 9 that, the algorithm has tracked the peak effectively and that, the PV array is operated at the corresponding V_{pp}. The power extracted from the PV array is depicted in Fig. 10.

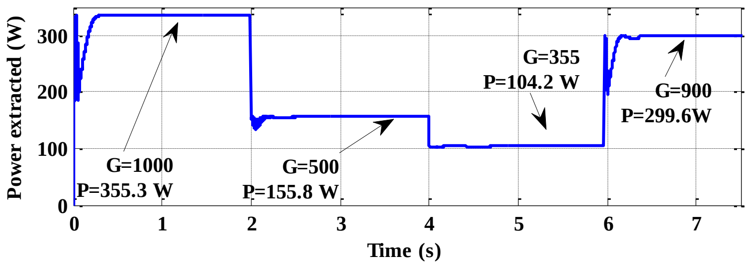

Fig. 10. Power extracted from the PV array

The power extracted from the PV array when G=1000 W/m^2 (unshaded) is 335.3 W. As the irradiation level changes from 1000 W/m^2 to 500 W/m^2, there is a change in power as the PV array is operated at 49.72 V (previous V_{pp}). The change in power is significant and the algorithm detects the change and initiates new search. The new peak power (155.8 W) is detected and the PV array is operated at the corresponding voltage (48.08 V). The irradiation is further changed from 500 W/m^2 to 355 W/m^2. The algorithm detects this change by the dip in power and generates new reference voltage. The tracked maximum power is 104.2 W and the corresponding voltage is 46.86 V. When the irradiation is increased from 355 W/m^2 to 900 W/m^2, the algorithm has effectively tracked the corresponding peak (299.5 W at 49.56 V) as shown in Fig. 10.

It is observable from the simulation results that the proposed DS MPPT algorithm tracks the maximum power point effectively and accurately under changing irradiation conditions. Once the peak is detected, the algorithm starts monitoring the power generated by the PV array periodically. The algorithm identifies the change in irradiation conditions if there is a significant deviation between the two successive power measurements. The algorithm then initiates new search.

5. Conclusions

The paper has proposed a new tracking algorithm based on Dichotomous search technique to track the maximum power of PV array under varying irradiation conditions. The proposed algorithm is explained in detail along with the pseudo code and the flow chart. The proposed algorithm is tested under full irradiation and dynamic irradiation conditions. The algorithm effectively tracked the peak point and the maximum power is extracted from the PV array under both the conditions. The simulated results show the ability of the algorithm to track the peak under rapidly changing irradiation conditions. However, the change in irradiation condition is assumed to be homogeneous.

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