A MODIFIED FIBONACCI SEARCH ALGORITHM FOR MAXIMUM POWER POINT TRACKING OF PHOTOVOLTAIC SYSTEM UNDER PARTIAL SHADING CONDITIONS

Akshaya K. Pati and Nirod C. Sahoo
School of Electrical Sciences
Indian Institute of Technology, Bhubaneswar-751013, Odisha, India
akshaya198310@gmail.com, ncsahoo@iitbbs.ac.in

ABSTRACT
The performance of Photovoltaic (PV) power system mainly depends on solar insolation and temperature. However, sometimes the performances of the PV systems are affected by partial shading of solar module due to cloud, dust, trees and some other nearby shading objects. During partial shading conditions, the PV characteristics exhibit local and global power maxima. Conventional maximum power point tracking (MPPT) algorithms fail to track the global maximum power point under above operating scenario. A new MPPT algorithm based on two important factors, i.e., study of power versus voltage characteristics of the PV array during partial shading condition and modified Fibonacci search algorithm, is proposed in this paper. The proposed algorithm is better than the conventional Fibonacci search algorithm in terms of power tracking capability of the PV system. Thus, the present proposition is more suitable for both uniform insolation and partial shading conditions. In this study, the PV system is connected with a DC motor and a battery through a bidirectional power converter. Modelling and simulation of the proposed algorithm are implemented on MATLAB/SIMULINK platform and the results are analyzed for validity of the proposed algorithm.

KEY WORDS
Fibonacci Search Algorithm, MPPT, Partial Shading, Photovoltaic Array

1. Introduction
The global energy demand is increasing day-by-day due to increase in population and urbanization. To meet the increasing energy demand, renewable energy resources are the only alternatives to the conventional resources such as coal, petroleum, natural gas etc. Among the available renewable resources, photovoltaic (PV) system is the most acceptable one, because it is pollution free, requires less maintenance and eco-friendly.

The basic component of a PV system is a PV cell. A number of PV cells are connected to form a PV module. The PV cell is a semiconductor diode consisting of a \( p-n \) junction which is exposed to solar insolation. Hence, PV cells exhibit nonlinear characteristics with respect to voltage and current output. The major drawbacks of PV system are its nonlinear characteristics and low energy conversion efficiency.

The power voltage (\( P-V \)) characteristics curve of a PV system under uniform insolation has a single peak, at which maximum power can be drawn from the PV system. To operate the PV system at that particular point, maximum power point tracking (MPPT) controller is required. Solar insolation varies with the time of a day, which changes the corresponding generation of power. Maximum power transfer occurs when PV source impedance matches with the load impedance irrespective of solar insolation. To attain maximum power, many algorithms have been proposed in the literature. The detailed overview of the MPPT algorithms has already been discussed and the comparisons are presented in [1]. Among available algorithms, the Perturb & Observation (P&O) and Incremental Conductance (IC) algorithms are most commonly used. The P&O algorithm is based on the principle that perturbation in the operating voltage of a PV array corresponds to change in power generation. If the given perturbation leads to an increase (decrease), the subsequent perturbation is generated in same (opposite) direction of operating voltage. In IC algorithm, the ratio of change in power to change in voltage is zero at maximum power point (MPP). These algorithms have difficulties to find MPP, under partial shading conditions (PSC). A modified hill climbing algorithm and the properties of \( P-V \) characteristics have been tested for MPPT under partial shading conditions [2].

Recently, many algorithms based on evolutionary computational techniques such as Genetic Algorithm (GA) [3], Differential Evolution (DE) [4], Particle Swarm Optimization (PSO) [5], and Ant Colony Optimization (ACO) [6] have been proposed. These methods have been tested for both partial shading and uniform insolation conditions. As these algorithms are complex in nature, the application of such algorithms in real time leads to a higher system complexity.

Some algorithms are also based on intelligent techniques such as Fuzzy Logic (FL) [7] and Artificial Neural Network (ANN) [8]. These algorithms work under both partial shading and uniform insolation conditions. For the implementation of FL, many fuzzy rules are required; whereas in case of ANN, many training data are necessary. So both the methods are practically not very much suitable for the implementation of MPPT. Similarly Fibonacci search algorithm also does not give guarantee to track the global maximum power for all possible shading patterns [9], [10].

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In the present study, a modified Fibonacci search algorithm and changed behaviour of $P-V$ curve under PSC have been used to find the global maxima.

This paper is organized as follows. Section 2 describes the PV system modeling under partial shading conditions. Section 3 discusses about the modified Fibonacci search algorithm to get the global maximum power. Section 4 describes about the system configuration. Section 5 describes about simulation results and discussion. Section 6 concludes the paper.

2. PV System Modeling under Partial Shading Condition

In a PV array, a number of PV modules are connected in series or parallel to produce desired voltage and current level. The basic building block of a PV cell is a current source in anti-parallel with a diode. The practical equivalent circuit of a PV cell is shown in Fig. 1 [11, 12].

![Fig. 1 Equivalent circuit of a PV cell](image)

The symbols in Fig.1 are defined as follows:

$I_s$: Current generated by the incident light;

$I_d$: Current through the parallel diode;

$D$: Parallel diode;

$R_p$: Parallel resistance;

$R_s$: Series resistance;

$I_{pv}$: PV output current;

$V$: PV output voltage.

From Fig. 1, current generated by a solar cell at a particular temperature and insolation is expressed as:

$$I_{pv} = I_s - I_d \left( \exp \left( \frac{q(V + I_{pv}R_s)}{nKT} \right) - 1 \right) - \frac{V - I_{pv}R_s}{R_p}$$

(1)

where, $I_s$ is reverse saturation current of a diode, $n$ is the diode ideality factor, $K$ is Boltzmann’s constant, $q$ is the electron charge, $T$ is the temperature in Kelvin.

The output of a PV cell is given by:

$$V = \frac{nKT}{q} \ln \left( \frac{I_{pv} - I_s + \frac{V - I_{pv}R_s}{R_p}}{I_s} + 1 \right) - I_{pv}R_s$$

(2)

When the solar insolation is uniform, the PV array exhibits a single peak in its $P-V$ characteristic. However in practice, all modules may not get equal insolation. Due to this there will be partial shading conditions among the PV modules. When a particular module receives low insolation than its nearby module, higher current generating module forces the low current generating module to operate at a higher current. As a result of this, the shaded cell may enter into the negative voltage operating region. This may lead to thermal breakdown of the PV cell, which is called hotspot effect. This effect can be avoided by using a bypass diode across some cells of the module. In practice, the bypass diode is placed across 15-20 series-connected cells. When the reverse saturation voltage of any PV cell exceeds the cut-in voltage of a diode, it enters into forward bias and thus the corresponding module is bypassed.

![Fig. 2 PV array with bypass diodes](image)

Fig. 2 shows three series-connected PV modules, each with a bypass diode. Here, PV3 being partially shaded by some near objects, so it receives less insolation as compared to PV1 and PV2. But, when the module is bypassed by a parallel diode, it will not generate any current. Under open circuit condition, the voltage of a cell is expressed as:

$$V_{oc} = \frac{nKT}{q} \ln \left( \frac{V - I_g}{R_p} \right) + 1$$

(3)

As shown in Fig. 2, D1, D2, D3 are the bypass diodes and D4 is a blocking diode which is connected in series with the PV array for protection of series connected PV string.

![Fig. 3 (a) P-V characteristics (b) I-V characteristics](image)

Fig. 3 shows the typical $P-V$ and $I-V$ characteristics of a PV array under uniform and partially shaded solar insolation. Here, when PV array receives uniform insolation of 900W/m², the $P-V$ ($I-V$) curve exhibits...
single peak (stair). When one of the PV module receives solar insolation of 400W/m², it is subjected to partial shading and multiple peaks (stairs) are exhibited on \( P-V \) curve.

3. Fibonacci Search based MPPT Algorithm

Here, a two-stage MPPT algorithm has been proposed to track the global maximum power under partial shading conditions. In the first stage, the MPPs of different regions are obtained by the \( P-V \) curve scanning process. In the second stage, the Fibonacci search algorithm is used to get the exact MPP.

The Fibonacci search method is based on reducing the search region in each iteration. In this method, the search region and two intermediate points in that region are initially defined. The locations of the intermediate points are based on the Fibonacci series. A typical Fibonacci search process is shown in Fig. 4.

![Fig.4 Fibonacci search process](image)

In the above figure, \( V_1 \) and \( V_2 \) are two extreme points of the search region, \( V_3 \) and \( V_4 \) are the two intermediate points in this region.

A Fibonacci series is expressed as:

\[
F_0 = 0, ~ F_1 = 1, ~ F_k = F_{k-1} + F_{k-2} \text{ for } k = 2, 3, \cdots \tag{4}
\]

where \( F_0, F_1 \) are the Fibonacci numbers.

The two intermediate points in between the initial search points are expressed as:

\[
V_3 = V_1 + \left( \frac{F_{k-1}}{F_{k-2}} \right) (V_2 - V_1) \tag{5}
\]

\[
V_4 = V_2 - \left( \frac{F_{k-1}}{F_{k-2}} \right) (V_2 - V_1) \tag{6}
\]

In the above equations, \( k \) is the iteration number, \( F_{n-1} \) and \( F_{n+1} \) are the \((n-1)\)th and \((n+1)\)th number of a Fibonacci series, respectively.

In the present study, search points and their function are taken as voltage (V) and power (P), respectively. In the Fibonacci search the two intermediate points and corresponding values are evaluated at first iteration and in subsequent iteration, only one intermediate point is evaluated. In Fig. 4, 1st iteration shows the search points and their corresponding function value. In the 2nd iteration, when the power at \( V_1 \) is less than the power at \( V_4 \), intermediate points are updated as given below:

\[
\begin{align*}
V_1 &= V_1 \\
V_2 &= V_2 \\
V_3 &= V_4 \\
V_4 &= V_2 - \left( \frac{F_{k-1}}{F_{k-2}} \right) (V_2 - V_1)
\end{align*}
\]

When the power at \( V_3 \) is more than power at \( V_4 \), the intermediate points are updated as:

\[
\begin{align*}
V_1 &= V_1 \\
V_2 &= V_4 \\
V_3 &= V_3 \\
V_4 &= V_1 + \left( \frac{F_{k-1}}{F_{k-2}} \right) (V_2 - V_1)
\end{align*}
\]

The search process is terminated when the search interval is less than a predetermined small value.

From the literature and practical data [2], it is known that the MPP is located near to 80% of the open circuit voltage (\( V_{oc} \)) of an unshaded PV module. Further, a series connected PV system exhibits multiple peaks in the \( P-V \) characteristic curve under partial shading conditions. The number of peaks on the \( P-V \) characteristic curve depends upon the number of PV modules being bypassed by the parallel diodes. Previously [2, 13], it has been reported that the minimum displacement between two successive peaks of a \( P-V \) characteristic curve under partial shading conditions is 80% of \( V_{oc} \) of a module. The above observation is used here to track the global MPP. Fig. 5 shows the \( P-V \) characteristic curve of a PV array consisting of six PV modules connected in series, where each module is having \( V_{oc} \) of 22.2V. Therefore, the open circuit voltage of this PV array is 135V.

![Fig.5 Peak points of \( P-V \) characteristic curve](image)

Here, P1, P2, P3, P4, P5 and P6 are the peak points on the \( P-V \) curve. The corresponding values of peak points are represented as X and Y for voltage and current, respectively. The PV array operating voltages are observed to be 14.42V, 32.88V, 52.41V, 72.61V, 93.91V and 115.3V at P1, P2, P3, P4, P5 and P6, respectively. Among these points, five are local peaks and one is the global peak. The differences between two consecutive
Fig. 6 Complete flowchart of the proposed MPPT algorithm

The complete flowchart of the proposed MPPT algorithm is shown in Fig. 6. In this context, the initial range for Fibonacci search is taken from \((V_{\text{max}} - V_{\text{oc}})\) to \((V_{\text{max}} + V_{\text{oc}})\). These two points and two intermediate points are represented as \(V_1\), \(V_2\), \(V_3\), and \(V_4\), respectively, as explained in Fig. 4. The search points are updated according to the flowchart. This process is continued until the search region is less than a predefined small value. For sudden change of solar insolation the proposed MPPT algorithm is reinitialized to find the GMPP [3].

4. System Description

The block diagram of complete system is shown in Fig. 7. It consists of a PV array, MPPT block, DC-DC boost converter, a battery through a bidirectional converter and a DC load. In this study, twelve series connected PV modules have been taken, with power rating of each as 85W under rated conditions. So the maximum power that can be obtained from the PV array is nearly 1kW under standard conditions. Voltage and current from the PV array are applied to the Fibonacci search based MPPT control block. The reference voltage and actual operating voltage of PV array are compared to generate the error signal. The pulse width modulation (PWM) generator is used to generate pulses for boost converter by considering the error signal. The boost converter is used here to match the impedance between the load and the PV source internal impedance by adjusting the duty cycle.
A = exponential zone amplitude (V)
B = exponential zone time inverse (V/\text{Ah})
V_{\text{bat}} = battery voltage (V)
R = internal resistance (Ω)
i = battery current (A)

5. Simulation Results & Discussion

The MATLAB/SIMULINK model of the complete system is shown in Fig. 9. The proposed MPPT algorithm is programmed using embedded function of SIMULINK. The PV array is composed of twelve series-connected PV modules with rated power of 85W. These PV modules receive different solar insulations to generate partial shading effect. In Fig. 10, the proposed MPPT algorithm is compared with the conventional Fibonacci search algorithm [9]. The solar insolation pattern for 0-2 second interval as specified in Table I, are considered for the comparative study. From the \( P-V \) characteristic, the two peak points are shown in Fig. 10. The conventional Fibonacci search algorithm is trapped a local peak corresponding power is 691W; whereas the proposed MPPT algorithm tracks the global peak which corresponds to 699W.

<table>
<thead>
<tr>
<th>Module Number</th>
<th>Time(Second)</th>
<th>Insolation(Watt/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2 sec (a)</td>
<td>2-4 sec (b)</td>
<td>4-6 sec (c)</td>
</tr>
<tr>
<td>1-3</td>
<td>900</td>
<td>860</td>
</tr>
<tr>
<td>3-6</td>
<td>600</td>
<td>800</td>
</tr>
<tr>
<td>7-9</td>
<td>900</td>
<td>1000</td>
</tr>
<tr>
<td>10-12</td>
<td>1000</td>
<td>760</td>
</tr>
</tbody>
</table>

Table I: Insolation patterns

For verification of the proposed algorithm under different partial shading conditions, different solar insulations are taken as shown in Table I. The \( P-V \) characteristic for each shading pattern is shown in Fig. 11 as a, b, c, and d, respectively. This is obtained by varying the load current from zero to short circuit current of the PV array. The tracking performances for each solar insolation pattern are shown in Fig. 12(a). For different
shading patterns, the proposed algorithm tracks the global maximum power point.

The specifications of battery and DC motor are given in Table II. The power demand for the DC motor load is 687.5W, which is shown in Fig 12(b). The charging/discharging of battery in terms of percentage of state of charge (SOC) are shown in Fig.12(c). It is seen that within a time period of 2 to 4 sec., the power demand by the load is less than the PV generated power. Hence, the surplus power is used here to charge the battery. On the other hand, for 4 to 6 sec. duration the generated power is not sufficient to the load demand so battery starts discharging to provide the deficit power. The DC link voltage of the bidirectional converter is shown in Fig. 12(d).

Table II: Battery and DC motor specification

<table>
<thead>
<tr>
<th>Battery</th>
<th>DC motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
<td>150V</td>
</tr>
<tr>
<td>Rated Capacity</td>
<td>5Ah</td>
</tr>
<tr>
<td>DC link reference voltage (V_{dc})</td>
<td>250V</td>
</tr>
<tr>
<td>Armature resistance and inductance</td>
<td>0.78Ω, 0.016H</td>
</tr>
<tr>
<td>Field resistance and inductance</td>
<td>150Ω, 112.5H</td>
</tr>
<tr>
<td>Field armature mutual inductance</td>
<td>1.234H</td>
</tr>
<tr>
<td>Total Inertia</td>
<td>0.05Kg.m²</td>
</tr>
<tr>
<td>Viscous friction coefficient</td>
<td>0.01 N.m.s</td>
</tr>
<tr>
<td>Field voltage</td>
<td>250V</td>
</tr>
<tr>
<td>Mechanical Torque</td>
<td>4.5N.m</td>
</tr>
</tbody>
</table>

6. Conclusion

In this paper, a new MPPT algorithm based on modified Fibonacci search algorithm and properties of P–V characteristic under partial shading condition is proposed. This algorithm is tested under rapidly changing solar irradiance and partial shading of PV array. The proposed method is converges towards the maximum power point more effective in comparison to the conventional Fibonacci search approach. This algorithm is tested for a DC motor load and a battery through a bidirectional power converter to maintain a constant DC voltage. The proposed method has offered good accuracy and tracking performance.

References


