Strategic Perturb and Observe Algorithm for Partial Shading Conditions

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Abstract

Solar Photovoltaic (PV) is one of the cheapest renewable resources of electrical energy. Its dependence on the connected load bounds its production capability. To deliver the determined power, it is required to operate at the Maximum Power Point (MPP) in the characteristic curve of the PV array. Tracking the MPP requires electronic circuits governed by MPP Tracking (MPPT) algorithms. The most simple, cheap, and softly implementable MPPT algorithm is “Perturb and Observe (P&O)”. It efficiently performs under Uniform Weather Conditions (UWC) but fails under Partial Shading Conditions (PSC) due to the formation of multiple peaks in the P-V characteristic curve of a PV cell. In this paper, weaknesses of the P&O algorithm are studied and overcome by structural modifications. The proposed structure is named the “strategic P&O algorithm”. Performance of the conventional and proposed algorithms is evaluated at the following standard benchmarks, tracking speed, tracking time, efficiency, and ability to track the Global MPP (GMPP) under PSC. Results have shown that the proposed SP&O algorithm has outperformed the conventional P&O algorithm under numerous weather conditions. Simulations are performed in MATLAB/Simulink.

Index Terms: DC/DC Converter, Maximum Power Point, MPP Tracking Algorithms, MATLAB/Simulink, Perturb and Observe.

1. INTRODUCTION

Solar Photovoltaic (PV) is one of the cheapest renewable resources of electrical energy [1], and [2]. The photovoltaic effect's direct conversion of solar irradiance into electrical energy makes it the most popular among all the renewable energy technologies. The research areas associated with this marvelous technology are materials efficiency, tracking of the Sun, and the dependence of power generation at the load [3]. The research on the materials of solar PV cells has achieved much improvement with 29.1% efficient gallium arsenide [4]. However, this part of the technology relates to chemical engineering. Further, the mechanical tracking of solar panels to follow the path of the Sun has almost achieved its peak with single, and dual-axis tracking [5]. The third and major problem is the inability of solar PV cells to produce maximum output power due to the load connected at its output [6], which could be overcome by operating the PV cell at its Maximum Power Point (MPP) [7]. The PV cell has non-linear characteristic curves with a peak known as the MPP, where it can generate maximum power if operated, as shown in figure I [3].

The MPP position depends on the illumination received by the PV cell and the surrounding temperature as shown in figure II [8]. Electronic circuits known as MPP trackers are employed to track the MPP location. These electronic converter circuits are governed by a set of commands called algorithms [9], and [10]. Which can be alienated into two:

1. Conventional algorithms are simple structured, easily implementable, and to code, and can efficiently track the MPP under Uniform Weather Condition (UWC), however, falls under Partial Shading Conditions (PSC) due to the formation of multiple peaks in the characteristic curve of a PV cell as shown in figure III [11]. Identification of the real or Global MPP (GMPP) among all the other local peaks is not possible for the conventional algorithms due to their searching strategies. The conventional algorithms include: (1) Perturb and Observe [12], (2) Incremental Conductance [12], (3) Hill Climbing [12], (4) Fractional Short Circuit [13], and (5) Fractional Open Circuit [14].

2. Soft computing algorithms, on the other hand, possess the ability to identify the GMPP under PSC but are complex in structure, hard to implement, demand huge memory, and require high cost for huge data training. The most known soft-computing algorithms are Particle Swarm Optimization [15], Genetic algorithm [16], Fuzzy Logic Controller [17], Artificial Neural Network [18], and Flower Pollination algorithm [19].

The ideal algorithm would have no drawbacks in both categories. Keeping in mind the strengths of both categories, it is better to work for the performance optimization of conventional algorithms rather than solving the almost impossible drawbacks of soft-computing algorithms.
In this research paper, a Strategic P&O (SP&O) algorithm is proposed, which is designed by modifying the searching strategy of the conventional P&O algorithm. Modifications have been made by keeping in view the target of designing a simple structure, easy to code, and cheap to implement, and easy to test under various weather conditions at standard benchmarks. When tested under numerous weather conditions, the proposed strategy has proved its superiority over the conventional P&O algorithm. Simulation is performed in MATLAB/Simulink. The paper is arranged as follows: Section II, explains the conventional P&O algorithm, Section III, describes the proposed SP&O algorithm, Section IV, presents the simulation and results of the P&O and SP&O algorithms, Section V, is the conclusion of the research, Section VI is acknowledgment, and Section VII, lists the references.

II. PERTURB AND OBSERVE ALGORITHM

The P&O algorithm utilizes the strategy of comparing the latest result with the previous and selecting the best one. Initially, it sets the duty cycle of the electronic circuit (DC/DC converter) at 0.5 and measure the Voltage (V), Current (I), and Power (P) output of a photovoltaic system against it. After assigning these initial values to the variables V, I, and P, the P&O algorithm proceeds for the tracking of MPP. In the second step, the P&O algorithm perturbs the value of voltage by changing the duty cycle and compares the change in power with the previous reading. If the change is positive, it continues the perturbation in this direction until the change in power for the change in voltage becomes negative. The negative change indicates that the P&O has crossed the MPP. Therefore, when the decrease in power is detected, it reverses the direction of perturbation and moves back towards the MPP. This steady-state oscillation does not allow the P&O to provide a stable output. The flow chart of the P&O algorithm is depicted in figure IV.

a) Strengths
1. Simple Structure
2. Easy to Implement
3. Cheap to Implement

b) Weaknesses
1. Slow Tracking Speed
2. Steady-State Oscillation
3. Fail to Track GMPP under PSC

c) Opportunities
1. Removal of Steady-State Oscillations
2. Improvement in Tracking Speed

Figure IV: Flowchart of Conventional Perturb and Observe Algorithm [20]

Figure I: Characteristic Curves of Solar Photovoltaic Cell [6]

Figure II: Relation of Illumination and Temperature to Characteristics of Solar Photovoltaic Cell [7]

Figure III: Partial Shading Effect on the Solar Photovoltaic Module [11]

Figure IV: Flowchart of Conventional Perturb and Observe Algorithm [20]
STRATEGIC PERTURB AND OBSERVE ALGORITHM

The conventional P&O algorithm performs various checks to decide the direction of perturbation. Each time after checking for the change in power it proceeds to another check for the change in voltage or current and decides the perturbation direction. This double-checking in each iteration affects the MPP tracking speed, efficiency, and the number of computations.

This double-check is removed by the proposed SP&O algorithm. The proposed strategy is to check just for the output power (which is the main concern) of a PV system and decide the direction of perturbation. It has increased the MPP tracking speed by 50%, and also reduces the tracking time with the same ratio of 50%.

Further, the issue of steady-state oscillations is due to the lack of decision power of the P&O algorithm. It could not decide the final input duty cycle that needs to be selected for attaining the MPP. The instability in the output power makes it unsuitable for most applications.

This issue is resolved in the proposed SP&O algorithm by selecting the optimal duty cycle. The operating procedure is:

- Accelerating the operating power point towards MPP with a large step size. The instant where the SP&O detects the MPP crossing, it reduces the step size by two and keeps moving the operating point in the reverse direction until another MPP cross is detected. After the second cross, it reduces the step size by four for once and selects the final output as MPP.
- No further change in the duty cycle will remove the steady-state oscillations.

The third weakness attached to the P&O algorithm is its MPP tracking speed.

It has been observed by the researchers that the MPP occurs close to 80% of open-circuit voltage and 90% of the short circuit current of a solar PV cell. Therefore, despite searching the MPP from the left-hand side of MPP, the SP&O has found it fruitful to begin its search from the right-hand side with large initial steps to reduce the MPPT time.

The flowchart of the proposed SP&O algorithm is presented in figure V. It depicts the obtained strategy clearly, which has been described in detail above in this section. Initially, after detecting the change in power the SP&O algorithm gets into operation. Set the operating point at an open-circuit voltage (Voc) and provide the first step toward MPP by initiating the first change in duty cycle “D=D+ΔD” for the first iteration only and this step will not be executed in upcoming iterations.

Further, it continues its propagation towards MPP with the same large step size until it makes the first cross to the MPP. After detecting the first cross the SP&O algorithm reverses the direction of tracking but with a small step size (equal to the half of initial step size) and keeps propagating until detects a second cross.

Comparison of the results under static and changing Uniform Weather Conditions (UWC) is conducted at the standard benchmarks such as; MPP tracking seed, steady-state oscillations, and the MPPT efficiency.

a) Uniform Weather Conditions

Under Uniform Weather Conditions (UWC) all the solar PV cell receives equal illumination level. The characteristic curve of the 90 Watt PV test module under UWC is shown in figure VII.
Strategic Perturb and Observe Algorithm for Partial Shading Conditions

The characteristic curve in figure VII has shown that the MPP of a 90 Watt solar PV system under STC occurs at 30 Volts, 3 Amperes, and 90 Watt. This means the maximum power that could be extracted from the solar PV test system under UWC is 90 Watt. The simulation results under UWC for both conventional and proposed strategic P&O algorithms are presented in figure VIII and summarized in table I.

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Strategic Perturb and Observe Algorithm for Partial Shading Conditions

It can be observed in figure VIII (a), that the conventional P&O algorithm has achieved 90 W in 0.0854 seconds but has steady-state oscillations. The duty cycle continuously oscillates between 0.0021 and 0.0039 after reaching the MPP which does not allow the output power to get stable. Whereas, the proposed SP&O algorithm has proved its superiority by attaining 90 W in just 0.0244 seconds with zero steady-state oscillations under UWC as depicted in the simulation results of figure VIII (b), i.e., Proposed Strategic Perturb and Observe Algorithm. Compared to the conventional P&O algorithm, the proposed SP&O algorithm has reduced the MPP tracking time by 71.4%, which is a huge success in tracking time.

Table I: Results of Conventional and Proposed Strategic P&O Algorithms under STC

<table>
<thead>
<tr>
<th>ALGO</th>
<th>Pout (W)</th>
<th>MPP (W)</th>
<th>Tracking Speed</th>
<th>Improvement in MPPT Speed</th>
<th>Steady State Oscillations</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>P&amp;O</td>
<td>90</td>
<td>90</td>
<td>0.0854</td>
<td>71.4 %</td>
<td>0.0012</td>
<td>100%</td>
</tr>
<tr>
<td>SP&amp;O</td>
<td>90</td>
<td>90</td>
<td>0.0244</td>
<td>Zero</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

b) Changing of Load

The performance of the SP&O algorithm is further evaluated for different loads. The results have been presented in figures, i.e., figure IX, figure X, and figure XI, and summarized in table II.

The results in figure IX, figure X, and figure XI have shown that the proposed SP&O algorithm has achieved the MPP for 50 ohms, 30 ohms, and 40 ohms loads in just 0.0431, 0.0338, and 0.0408 seconds respectively with 100% efficiency.

The results have been summarized in table II.

Table II: Results of Proposed Strategic P&O Algorithms for Different Loads

<table>
<thead>
<tr>
<th>ALGO</th>
<th>Pout (W)</th>
<th>MPP (W)</th>
<th>Tracking Speed</th>
<th>Load Ohms</th>
<th>Steady State Oscillations</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP&amp;O</td>
<td>90.13</td>
<td>90</td>
<td>0.0244</td>
<td>20</td>
<td>Zero</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>90.08</td>
<td>90</td>
<td>0.0338</td>
<td>30</td>
<td>Zero</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>90.08</td>
<td>90</td>
<td>0.0408</td>
<td>40</td>
<td>Zero</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>90</td>
<td>0.0431</td>
<td>50</td>
<td>Zero</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure IX: Performance of Proposed SP&O with different 50 ohms Load

Figure X: Performance of Proposed SP&O with different 30 ohms Load
V. CONCLUSION

In this research article, we have optimized the performance of the most renowned conventional “P&O” algorithm under UWC for the standalone solar PV system. After incorporating the calculated changes in the structure of the P&O algorithm, it is noticed that the proposed structure named “Strategic P&O” has provided remarkable results in tracking speed, tracking time, and efficiency, compared to the conventional perturb and observe algorithm with different loads.

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Authors Contributions

The author, Muhammad Mateen Afzal Awan, confirms sole responsibility i.e., study conception and design, data collection, analysis and interpretation of results, manuscript preparation, technical implementation and computer formatting.

Conflict of Interest

The authors declare no conflict of interest and confirm that this work is original and not plagiarized from any other source.

Data Availability Statement

The testing data is available in this paper.

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References


