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Optimized hill climbing algorithm for an islanded solar photovoltaic system

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ABSTRACT

Conventional energy generation technologies face unreliability due to the depletion of fossil fuels, soaring energy prices, greenhouse gas emissions, and continuously increasing energy demand. As a result, researchers are searching for reliable, cheap, and environmentally friendly renewable energy technologies. Solar photovoltaic (PV) technology, which directly converts sunlight into electricity, is the most attractive sustainable energy source due to the sun's ubiquitous presence. However, the non-linear behaviour of solar PV demands maximum power point tracking (MPPT) to ensure optimal power production. Although Hill Climbing (HC) is a simple, cheap, and efficient MPPT algorithm, it has a drawback of steady-state oscillations around MPP under uniform weather conditions. To overcome this weakness, we propose some modifications in the tracking structure of the HC algorithm. The proposed optimized HC (OHC) algorithm achieves zero steady-state oscillations without compromising the strength of the conventional HC algorithm. We applied both algorithms to an off-grid PV system under constant and changing weather conditions, and the results demonstrate the superiority of the proposed OHC algorithm over the conventional HC algorithm.

1. Introduction

Conventional energy resources are going to depletion state that is serious concern of modern world [1]. Additionally, the greenhouse gas emissions, heightening energy generation, distribution and utilization has forced the world to look for a better alternate [2]. Reliable, renewable and sustainable energy generation resources are the ultimate solution to the above-mentioned problems [3]. Reliable presence of sun all around the world each day for a specific period of time makes it the most suitable renewable energy source [4]. The translation of solar illumination into the electrical energy in a single step with minimum losses using a concept of photoelectric effect makes solar photovoltaic the most promising renewable and sustainable energy technology [5]. Problems associated with the solar PV cell is its non-linear characteristics, which resists the production of maximum possible power [6]. To extract optimal power, it is mandatory to operate the solar PV system at its maximum power point (MPP) [7]. The operating point, where the PV cell can deliver its maximum is called the MPP [8]. The characteristic curve of solar PV cell is presented in the Fig. 1 that could easily explain the concept of MPP [7, 9]. The y-axis represents power and the x-axis represents voltage. The MPP is denoted by a green dot.

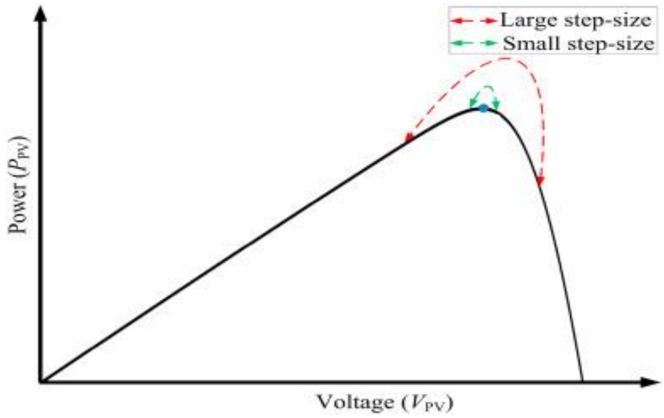


Fig. 1. Characteristic curve of a solar photovoltaic cell [7]

Detecting the position of MPP is the main task, which is performed by the converter driven by an algorithm. The mostly known MPP tracking (MPPT) algorithms includes, hill climbing (HC) [10], perturb and observe (PandO) [11, 12], fractional short circuit [13], and fractional open circuit [14]. The commonly used algorithm for MPPT in the market is HC. The HC is cheap and easy to implement but the drawback of steady state oscillations could not be overcome [10]. Multiple researchers have proposed various modification and improvements in HC technique. Although, they have attained certain goal and the reduction in oscillations around the MPP was the major achievement, but the steady state oscillation is still there.

"A Modified Hill Climbing MPPT Algorithm for Photovoltaic Systems" by H. P. Raharjo and S. S. Prianto [15]. This paper proposes a modified hill climbing algorithm with a damping factor to reduce steady state oscillations.

"A Novel Adaptive Hill-Climbing MPPT Algorithm for Photovoltaic Systems" by Y. Zhou, Z. Zhang, and X. Wang [16]. This paper proposes an adaptive hill climbing algorithm with a damping factor that changes with the solar irradiation level to reduce steady state oscillations.

"A New HC MPPT Method for PV Systems with Reduced Steady-State Oscillation" by A. Belmokhtar and A. Mellit [17]. This paper proposes a new hill climbing algorithm with a modified perturbation step to reduce steady state oscillations.

"A Novel HC MPPT Algorithm for Photovoltaic Systems with Reduced Steady-State Oscillations" by S. M. Islam, M. M. Islam, and M. Hasan [18]. This paper proposes a novel hill climbing algorithm with a variable perturbation step to reduce steady state oscillations.

Further, its basic tracking strategy is very powerful. Therefore, in this research article we have explored the working strategy of HC algorithm and proposed some modifications after deeply analysing the weaknesses and strengths in order to improve its performance in term s of efficiency and tracking time. The result has shown tremendous improvements in the efficiency and tracking time of HC algorithm comparing to the conventional HC algorithm.

The paper is ordered as follows: section-2, explain the conventional HC algorithm, section-3, presents the proposed optimized HC algorithm, section-4, describes and compare the results of HC and proposed OHC algorithms, section-5, concludes the research, and section-6, lists the references utilized in this research article.

2. Hill Climbing Algorithm

The HC algorithm collects the on-time data of solar PV cell/array and computes the next step. The data gathered by the HC algorithm includes the running voltage and current of PV system. It then computes the power. Further, it alters the current or voltage of PV system and measures the change in power. If the change is positive, it continues the alteration otherwise it reverses the direction of alteration until reaches the MPP. The problem arises when it struggles to settle down. This MPP tracking strategy can take it to the MPP but dos allow to settle, which cause continuous toggling of operating power point around the MPP. The flow chart of HC algorithm is presented in the

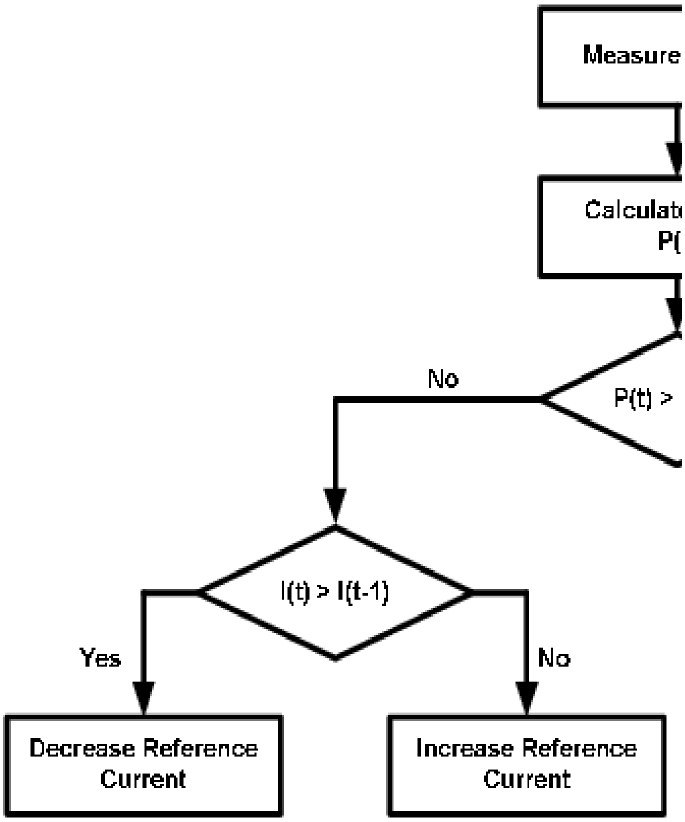


Fig. 2.

Here are the steps of the Hill Climbing algorithm:

Initialize: Start with an initial solution. This could be a random solution or a solution based on some heuristics.

Evaluate: Evaluate the initial solution by computing its fitness function value. The fitness function is a function that takes a solution and returns a score that represents the quality of the solution. The fitness function should be designed such that higher scores correspond to better solutions.

Generate Neighbours: Generate a set of neighbouring solutions by making small changes to the current solution. This step is where the name "Hill Climbing" comes from because it's like climbing up a hill by moving to adjacent points that are higher up.

Evaluate Neighbours: Evaluate the fitness of each neighbouring solution.

Select Best Neighbour: Select the neighbour with the highest fitness value. If this neighbour has a higher fitness than the current solution, replace the current solution with this neighbour and repeat the process from step 3. If none of the neighbours have a higher fitness than the current solution, terminate the algorithm and return the current solution as the local maximum.

Repeat: Repeat steps 3 to 5 until the algorithm reaches a local maximum.

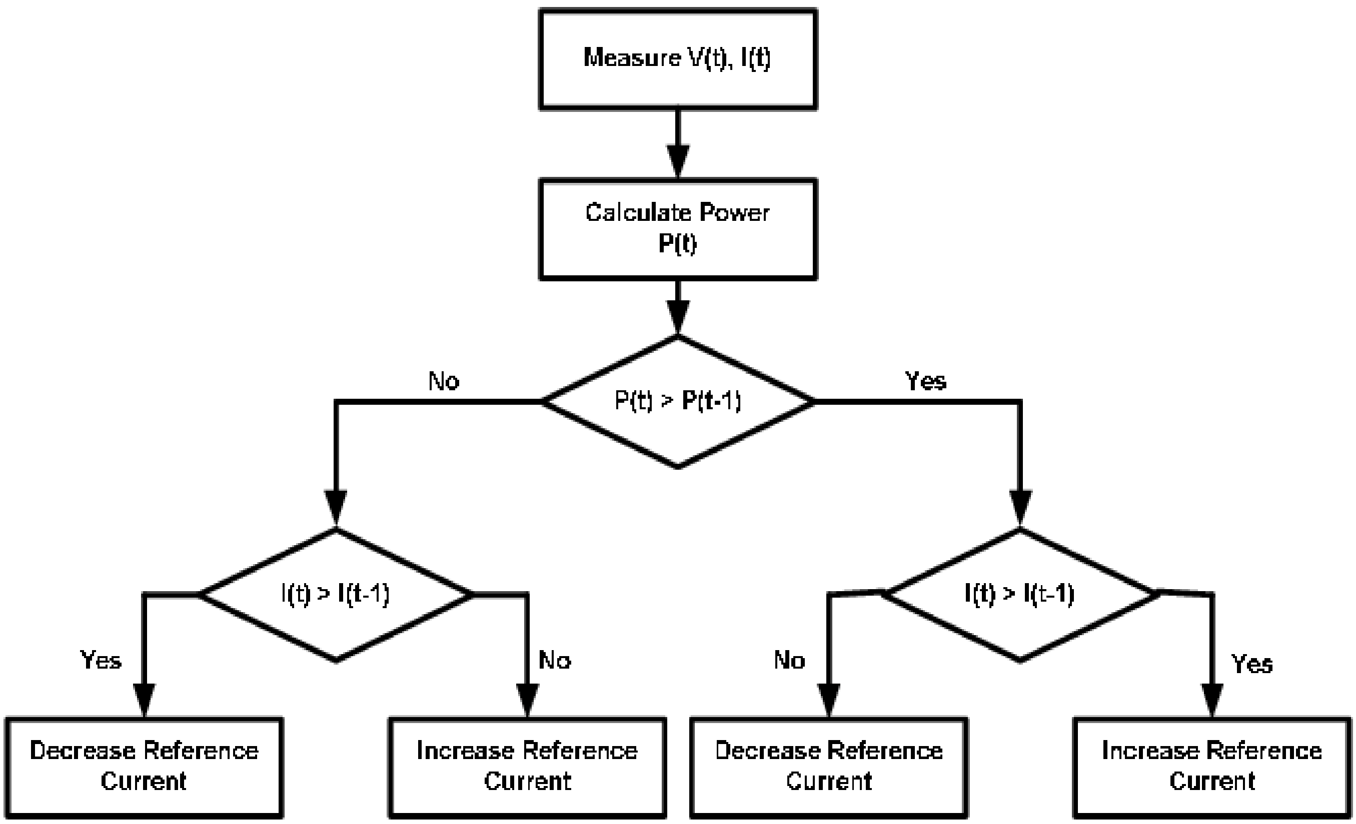


Fig. 2. Flowchart of hill climbing algorithm

3. Drawbacks/Weaknesses of HC Algorithm

The HC algorithm has the following drawbacks that needs to be optimized:

Slow Convergence: The HC MPPT algorithm can be slow to converge, especially in situations where the panel is subject to rapidly changing environmental conditions. This can result in a loss of energy output.

Sensitivity To Initial Conditions: The HC MPPT algorithm is sensitive to the initial conditions and may not always converge to the optimal solution if the starting point is not close to the maximum power point.

Oscillations: The HC MPPT algorithm may cause the system to oscillate around the maximum power point, which can result in excessive wear and tear on the equipment.

Limited Tracking Range: The HC MPPT algorithm may not be able to track the maximum power point if the panel's operating conditions are beyond a certain range.

Difficulty In Handling Partial Shading: The HC MPPT algorithm can have difficulty in handling partial shading of the solar panel, which can cause it to converge to local maxima rather than the global maximum power point.

High Computational Requirements: The HC MPPT algorithm requires high computational requirements, which can make it unsuitable for use in low-cost and low-power systems.

Lack of Robustness: The HC MPPT algorithm may not be robust enough to handle the wide range of operating conditions that can be encountered in real-world applications.

4. Optimized Hill Climbing Algorithm

In the proposed optimized hill climbing algorithm (OHCA), we have optimized the settling strategy of operating power point. Initially the data is collected from the solar PV array to compute the power. The voltage is incremented by changing the duty cycle. The change in power is measured. Based on the change in power the proposed OHCA proceeds towards the MPP. After attaining the MPP it starts toggling like the conventional HC. At the first reverse step of toggling, the OHCA reduces its stepsize to half and will continue proceeding back towards the MPP with the reduced stepsize. As the operating point crosses the MPP in reverse direction the OHCA further reduces it stepsize by four and step forward. At the first forward step towards MPP with one fourth stepsize the OHCA attains the MPP position and hold the operating point their by terminating the tracking procedure. This would remove the oscillations completely and the system would get the required output with zero steady state oscillations. Further, a strategy for detecting the change in weather outside without using the temperature or illumination sensors, has been developed. The OHCA after settling the power output will detect the change in weather by detecting the change in voltage and current using Eq.1, and Eq.2 respectively. The threshold values for the change in voltage and current have been set using hit and trial method and therefore will vary with the size of PV system. The flow chart of the proposed optimized HC algorithm is presented in the Fig. 3.

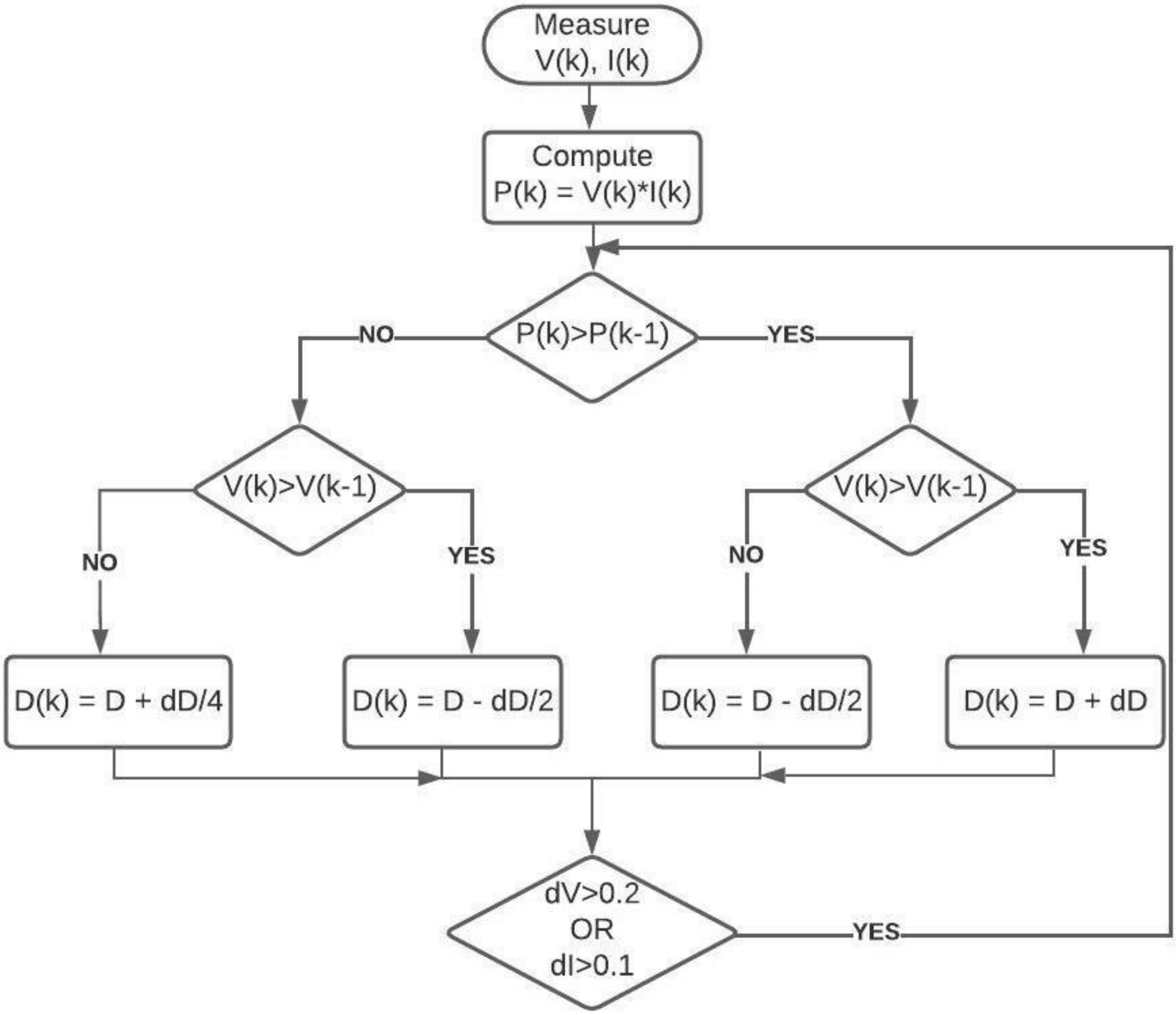


Fig. 3. Flowchart of the proposed optimized hill climbing algorithm

$$\Delta V = \frac{Vpv(t) - Vpv(t-1)}{Vpv(t)} \geq 0.2 \quad \ldots \tag{1}$$

$$\Delta I = \frac{Ipv(t) - Ipv(t-1)}{Ipv(t)} \geq 0.1 \quad \ldots \tag{2}$$

Here, the ΔV, ΔI, Vpv, Ipv, and t represents the change in voltage, change in current, voltage at the output of solar PV module, current of the PV module, and time respectively. The change in voltage if exceeds the 0.2volts, or if the change in current exceeds the 0.1 ampere, it alarms the change in atmosphere outside and of-course the change in the position of MPP. Here the algorithm will rerun to track the latest position of MPP.

5. Approach Comparison

The comparison of approaches of the conventional and proposed optimized HC algorithm is summarized in the table below.

Table 1

Comparison of Approaches of HC and OHC Algorithms

Hill Climbing Algorithm	Optimized Hill Climbing Algorithm
Used a fix step size	Reduces to the step size to zero
Steady state oscillations	Zero steady state oscillations
Unable to detect the change in weather	Possess the ability to detect the change in weather

Could not provide a fixed final output	Provide the fix output and wait to rerun if the change in weather occurs.
Using current as a control variable	Use duty cycle as a control variable

6. Results and Discussion

The OHCA and the conventional HCA are compared at the standalone solar PV system using the Simulink presented in the Fig. 4. A simulated standalone system is composed of a solar PV module, a DC-DC boost converter, MPP tracker, and a DC load. The algorithms are implemented in the MPP tracker module to drive the DC/DC converter.

The characteristic curve for the simulated system has been plotted and presented in the

Fig. **5**. The complete information about the behaviour of the PV system and the position of MPP has been can be observed in the characteristic curve. Here, the MPP occurs at 40-volts, 3-amperes, and 120-watts.

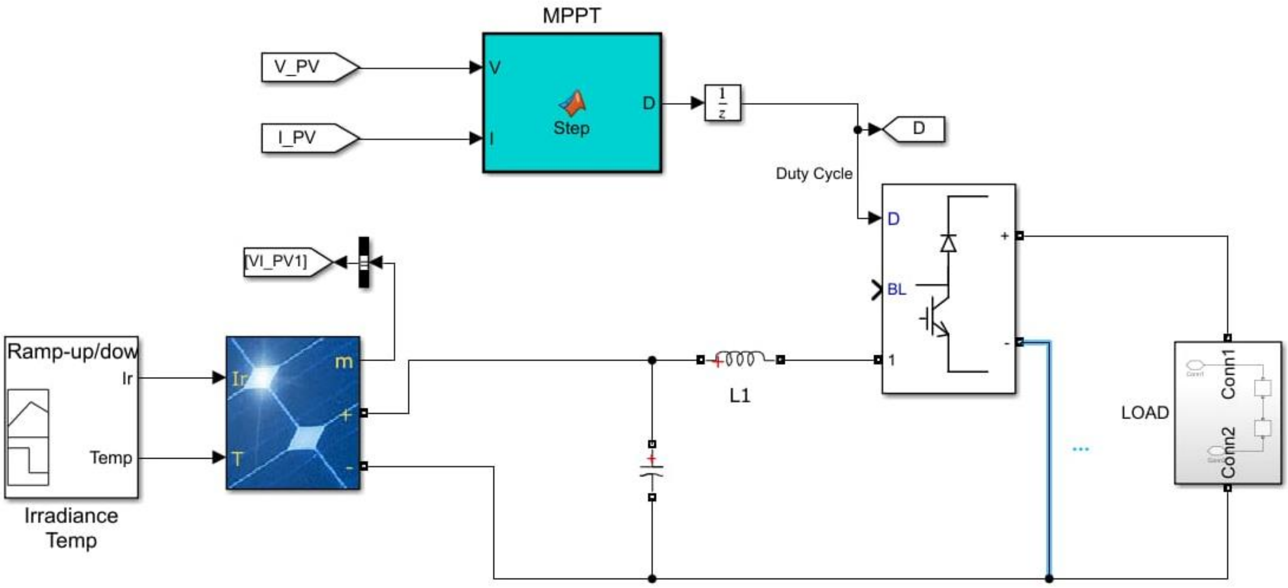


Fig. 4. Standalone solar photovoltaic system

Both the conventional HC and the proposed OHC algorithms have been applied at the designed 120Watt standalone solar PV system. The operating voltage and current at the MPP (that is 120-Watt) under uniform weather condition are 4-volts and 3-Amperes as depicted in the

Fig. **5**. The conventional HC algorithm when applied to the PV system, it provides the oscillating output of 0.2-watts between 119.7-watts and 119.9-watts. It can be clearly observed in the Fig. 6 that oscillations of 2-watts occur due to the instability of duty cycle. The reason for this instability is the natural behaviour of the conventional HC algorithm. Whereas, the proposed OHC algorithm has provided a stable output of 119-watts with 99.92% efficiency. It can be clearly observed in the Fig. 6, that the reason for this stable output is the fix duty cycle attained by the OHC algorithm. The strategy for taking the operating point to the MPP and keeping it stable has been explained in detail in the design of OHC algorithm.

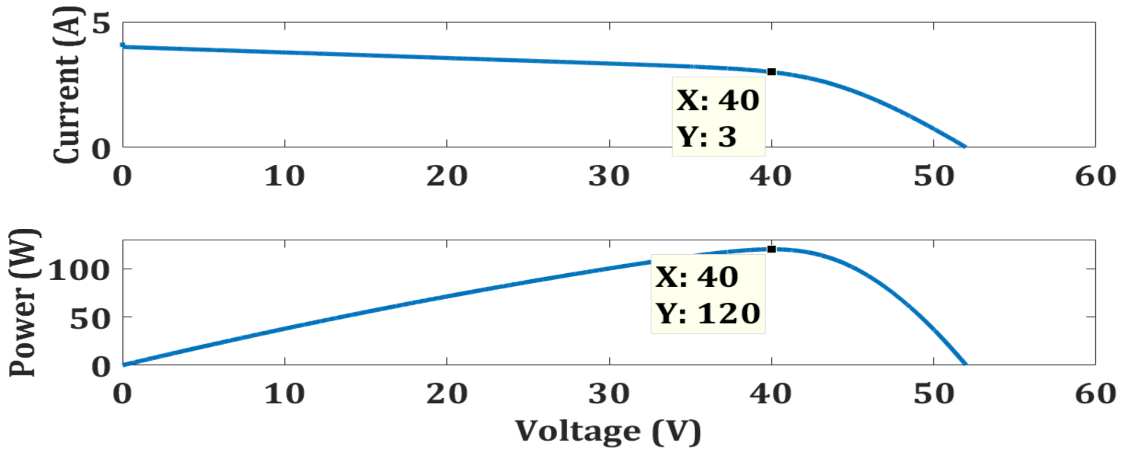
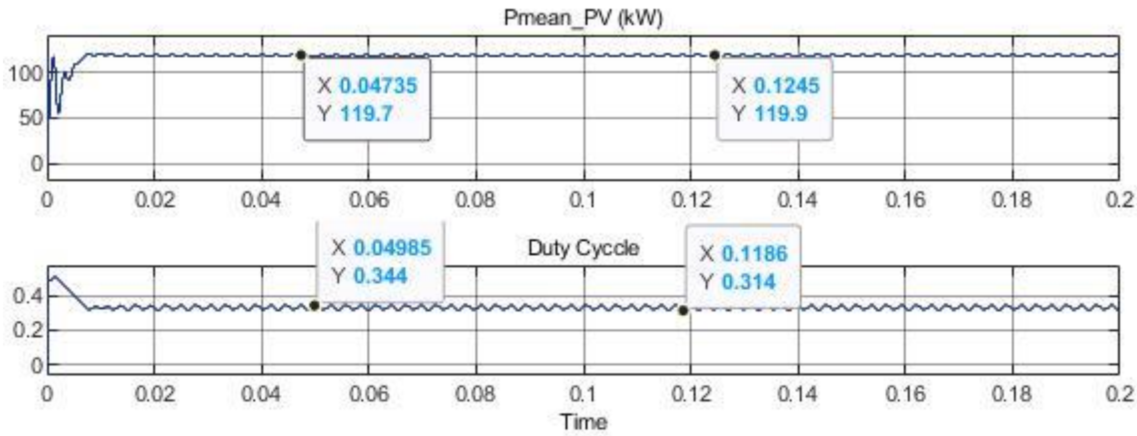
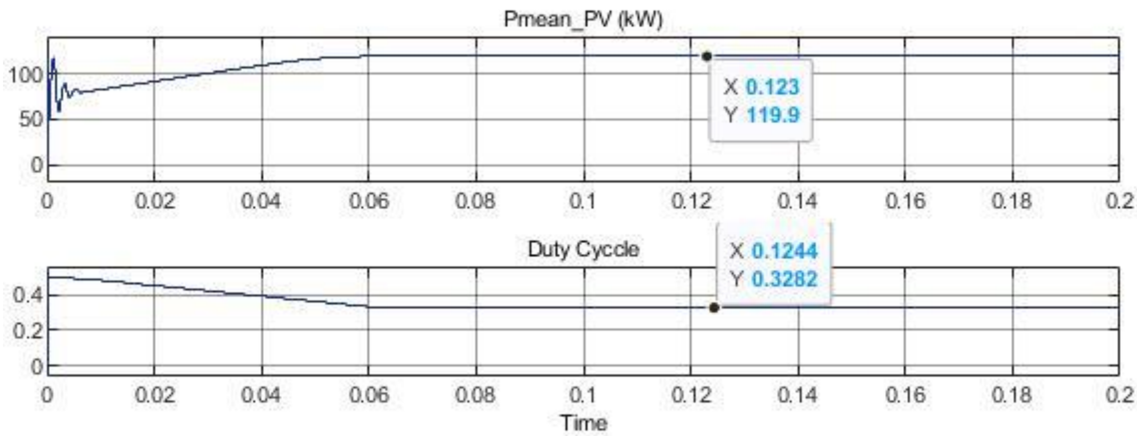


Fig. 5. Characteristic curve for a standalone photovoltaic system



Conventional Hill Climbing Algorithm



Proposed Optimized Hill Climbing Algorithm

Fig. 6. Results of conventional Hill Climbing and Optimized Hill Climbing Algorithms for a 120-Watt Photovoltaic System

Table 2

Performance comparison of the conventional and proposed optimized hill climbing algorithm.

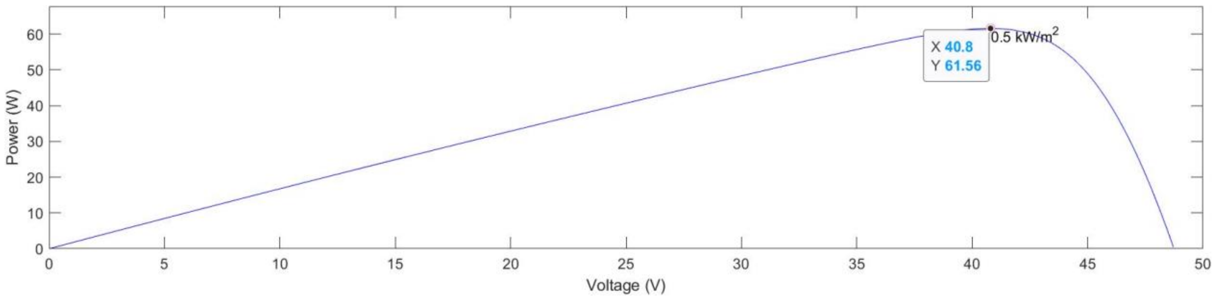
Algorithm	Steady State Oscillations	Ability to Detect the Change in Weather	Expected Output (W)	Extracted Power Output (W)	Efficiency (%)
Hill Climbing	0.2 Watt	No	120	119.7-119.9	Varying
Optimized Hill Climbing	Zero	Yes		119.9	99.92

A performance comparison among the conventional and the proposed optimized HC algorithm is summarized in Table 2, that explains the superiority of the OHC algorithm over the conventional HC algorithm by having zero steady state oscillations a stable output, and ability to detect the change in weather. Further, the detection of change in weather by observing the behaviour of variables (voltage and current) is performed and expressed in the

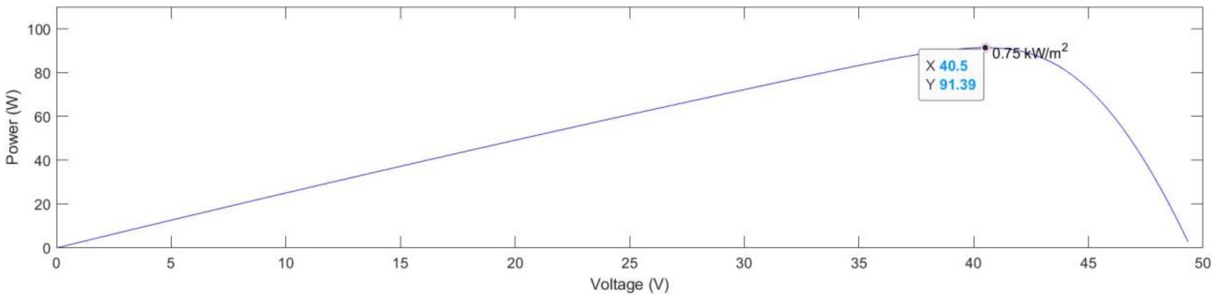
Fig. **7**. The illumination level selected for the change in weather are 750W/m2 and 500W/m2. The basic purpose of selecting different level of illumination level is to verify the changing weather detection capability of the proposed OHC algorithm. Therefore, any illumination value could be selected, we prefer these values due to their balanced difference from the standard test condition that is 1000W/m2. The application of changing weather is applied with the time span of 0.2-seconds. The characteristic curve for the changing illumination scenarios is presented in the

Fig. **7**, along with the achieved results by the proposed OHC algorithm. The position of MPP at 750W/m2 drops to 91.39Watts from 120Watts at 1000W/m2 and at 500W/m2 the MPP occurs at 61.56Watts as shown in

Fig. **7**. The OHC algorithm efficiently detect the change in weather and accurately tracked the MPP by trigger the action. The OHC algorithm has achieved the output of 119.9-watt, 91.33-watt, and 61.4-watt at 1000W/m2, 750W/m2, and 500w/m2 with 99.92%, 99.93%, and 99.74% efficiency respectively. Further, the performance of the proposed OHC algorithm is summarized in the Table 3.



A) Characteristic Curve of 120-Watt PV system at 500-W/m2



B) Characteristic Curve of 120-Watt PV system at 750-W/m2

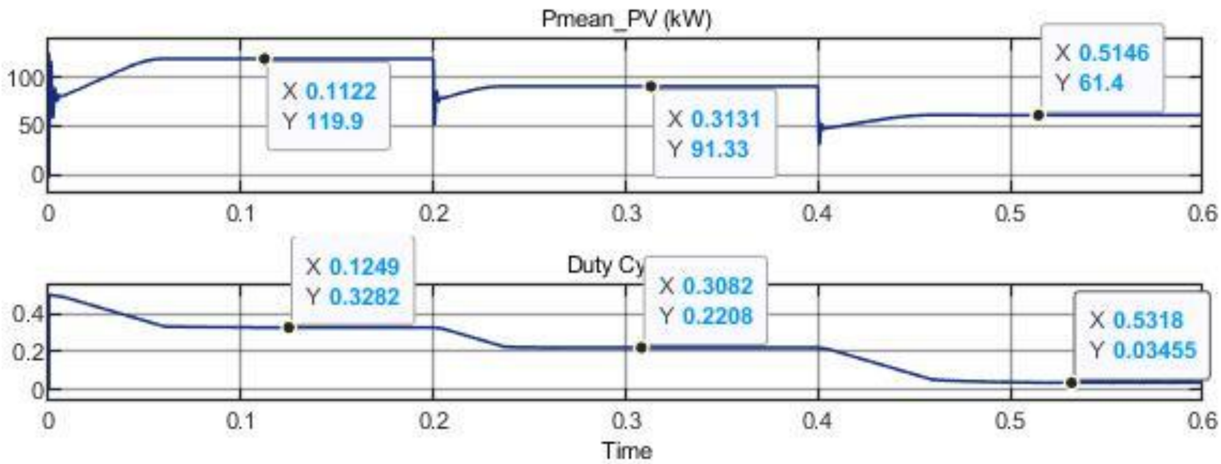


Fig. 7. Performance of the optimized hill climbing algorithm under changing weather conditions

Table 3

Performance summary of the proposed optimized hill climbing algorithm

Algorithm	Weather Conditions	Load (OHM)	Expected Output (W)	Extracted Power Output (W)	Efficiency (%)
Optimized Hill Climbing	1000W/m2	50	120	119.9	99.92
	750W/m2		91.39	91.33	99.93
	500W/m2		61.56	61.4	99.74
	1000W/m2	40	120	119.9	99.92
	750W/m2		91.39	91.33	99.93
	500W/m2		61.56	61.4	99.74
	1000W/m2	30	120	119.9	99.92
	750W/m2		91.39	91.33	99.93
	500W/m2		61.56	61.4	99.74
	1000W/m2	20	120	119.9	99.92
	750W/m2		91.39	91.33	99.93
	500W/m2		61.56	61.4	99.74

The data in Table 3 has summarized the performance of OHC algorithm four different loads under multiple weather conditions. Starting with maximum load of 50-ohm and proceeding to the minimum load of 20-ohm with the difference of 10-ohm has been applied to the standalone solar PV system. For each load the OHC algorithm retained its output and perform efficiently by operating the solar PV system at its MPP. These results have proved the worth of the proposed algorithm under uniform weather conditions. The change of lad has no impact on the performance of the OHC algorithm.

7. Conclusion

The penetration of renewable energy technology in the energy generation sector is a promising approach towards achieving sustainable and clean energy goals. Among renewable energy technologies, solar photovoltaic holds great promise, but its effective and efficient utilization requires MPPT circuits governed by an algorithm. Hill Climbing (HC) is a simple, effective, and cheap MPPT algorithm for uniform weather conditions, but its steady-state oscillations make it unattractive for multiple purposes. In this research article, we proposed an optimized version of the HC algorithm with zero steady-state oscillations. We implemented both the conventional and optimized HC algorithms on a 120-Watt standalone solar photovoltaic system and performed simulations for constant and changing weather conditions. The proposed OHC algorithm successfully achieved the MPP without oscillations, and we observed zero steady-state oscillations of the operating power point around the MPP under all circumstances. Our results demonstrate the superiority of the proposed OHC algorithm and its potential to make operation at the MPP possible without oscillations. This optimized HC algorithm can be a valuable addition to the field of solar PV technology and can help increase the efficiency and reliability of renewable energy systems.

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