

Maximum Power Point Tracking System Using Hill Climbing to Improve Solar Power Performance

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ABSTRACT

This study compares the performance of conventional and modified hill climbing MPPT algorithms on solar panels in achieving maximum power under varying irradiance conditions. The modified hill climbing algorithm proves superior in reducing tracking time, lowering power oscillation levels, and increasing output power compared to the conventional method. Testing with irradiance variations shows that the modified algorithm is more responsive to environmental changes, allowing maximum power to be achieved more quickly and stably. The results of this study demonstrate that the implementation of the modified hill climbing algorithm significantly improves the efficiency of solar power systems, offering potential performance optimization for solar energy applications under various operational conditions.

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1. INTRODUCTION

Energy plays a vital role in human life, and with rapid technological advancements, energy demand has significantly increased. Fossil energy sources such as oil, coal, and natural gas have dominated daily life, yet this reliance brings various issues. These energy sources are non-renewable, subject to price fluctuations, and have negative environmental impacts. Therefore, alternative energy sources that are sustainable, environmentally friendly, and economical are needed. Renewable energy offers a solution to meet energy needs while addressing the limitations of fossil fuel [1]. One form of renewable energy application is solar power plants. Solar power plants are a technology that can convert solar energy into electrical energy by applying the principle of the photovoltaic effect [2]. The use of photovoltaics offers advantages such as zero pollution, no emissions, and easy maintenance [3]. During operation, photovoltaics are influenced by two factors: light and temperature. Daily fluctuations in light and temperature conditions pose challenges for photovoltaics in generating maximum power [4]. Photovoltaic performance can be further optimized by implementing the MPPT method [5].

Maximum Power Point Tracking (MPPT) is a method that functions to increase voltage and current values, thereby maximizing the output power of a solar panel [6]. MPPT consists of three types: conventional MPPT, artificial intelligence (AI)-based MPPT, and hybrid MPPT. Each type of MPPT has its own drawbacks; for instance, conventional MPPT can cause high oscillations and may be unstable or fluctuate [7]. AI-based MPPT has disadvantages such as complex implementation and high costs [8]. Similarly, hybrid MPPT shares drawbacks with AI-based MPPT, including complexity and high costs [9]. The MPPT method continues to be refined, resulting in various algorithms tailored to different photovoltaic conditions, one of which is the hill climbing algorithm [10]. The hill climbing method is an MPPT technique that adjusts the duty cycle of the converter based on changes in photovoltaic power and voltage. The duty cycle value is altered until the photovoltaic voltage rises and power increases. If power increases, the duty cycle is updated

in the same direction; however, if power decreases, the duty cycle direction is reversed from the initial position [11]-[15].

MPPT with the hill climbing algorithm maximizes the power output from the solar panel by adjusting the duty cycle on the boost converter. The hill climbing method is modified to suit the needs of the solar panel; during operation, this method increases power up to the maximum point. If the maximum power has not been reached, the hill climbing method will continue adjusting until the solar panel reaches the maximum point. The research conducted is related to the Maximum Power Point Tracking (MPPT) system, but this research uses conventional methods to develop. The reason the author uses this method is that conventional methods are simpler in design, have low program complexity and are relatively cheaper in terms of cost.

2. METHOD

This research was conducted in the form of application of the MPPT hill climbing system on solar panels. In testing the performance of the MPPT hill climbing algorithm, irradiance will be changed by observing the output current, voltage and tracking time. The conventional MPPT hill climbing algorithm will be compared with the modified hill climbing algorithm based on the data that has been taken. The block diagram in Figure 1 illustrates the MPPT system design developed in this study. This system utilizes a 100 WP solar panel as the main energy source. A boost converter is used to regulate the output voltage generated by the solar panel, raising the voltage to match the load requirements. The system also includes control utilizing the hill climbing MPPT algorithm to ensure the generated power consistently remains at the maximum point, thereby optimizing the energy conversion efficiency of the solar panel.

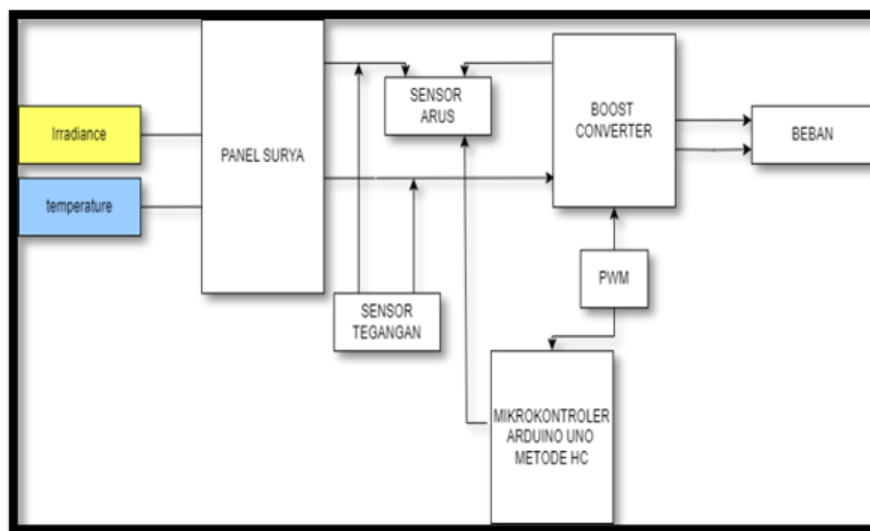


Figure 1. Hill climbing block diagram

Solar panel converts sunlight into electrical energy (DC). This electrical energy passes through current and voltage sensors, which detect the output current and voltage. The Arduino operates the MPPT algorithm using the hill climbing method. Hill climbing receives data to calculate the solar panel's output power ($P_{\text{photovoltaic}}$) and seeks the MPP. The hill climbing algorithm compares the current output power with the previous power. If the power increases, the duty cycle is slightly raised; if the power decreases, the duty cycle is slightly reduced. This process repeats until the output power reaches its maximum. The boost converter uses a PWM signal to control the duration of the MOSFET in the ON state, thus affecting the output voltage level. The higher, stabilized output voltage from the boost converter is then directed to the load for use. The boost converter used as the power circuit in this study has the primary function of stepping up the voltage from the solar panel source. The output voltage of this boost converter is influenced by the duty cycle, which is a crucial factor in the voltage regulation process. This regulation is essential for the MPPT algorithm to operate optimally and maintain the maximum power point. The designed boost converter has an input voltage of 18 V and an output voltage of 36 V.

Figure 2 shows the hill climbing algorithm system, the process begins by reading the voltage value $V(k)$ and current $I(k)$ generated by the solar panel. From these two values, the power $P(k)$ is calculated using

the formula $P(k)=V(k) \times I(k)$. Furthermore, the newly calculated power is compared with the previous power $P(k-1)$. If the new power is greater than the previous power $P(k) > P(k-1)$, it means that the system is moving in the right direction towards the maximum power point, and the duty cycle is changed by adding or subtracting values according to the gradient of the power change or slope. If the new power is less than or equal to the previous power $P(k) \leq P(k-1)$, the direction of the duty cycle change is reversed to improve the search direction towards the maximum point. After each iteration, the previous power value is updated so that it can be compared in the next cycle. With this approach, the algorithm gradually and continuously adjusts the duty cycle until it finds the maximum power point of the solar panel.

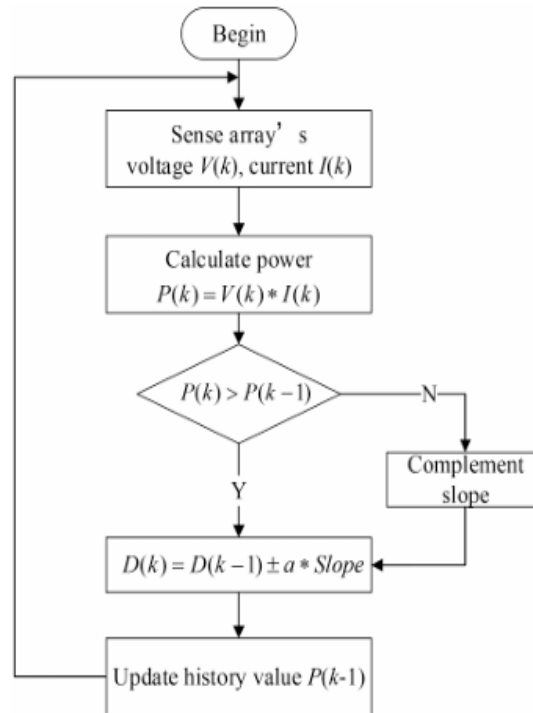


Figure 1. Conventional hill climbing algorithm [12]

The modified hill climbing algorithm in Figure 3, starts by measuring the voltage and current generated by the solar panel. From these two parameters, the output power is calculated by multiplying the voltage $V_{(pn)} [n]$ and the current $I_{(pn)} [n]$. Next, the algorithm calculates the change in voltage power ($\Delta V_{(pv)}$) by comparing the current power with the power in the previous iteration, and the change in duty cycle (ΔD) by comparing the current duty cycle with the previous one. When there is an increase in power ($\Delta P_{photovoltaic} > 0$), the algorithm checks the change in duty cycle. If the current duty cycle is greater than the previous one ($\Delta D > 0$), the duty cycle will be increased to increase the power further. Conversely, if $\Delta D \leq 0$, the duty cycle will be reduced to maintain power stability. On the other hand, if the power decreases ($\Delta P_{photovoltaic} \leq 0$), the algorithm will try to adjust the duty cycle inversely, if $\Delta D > 0$ the duty cycle is reduced, and if $\Delta D \leq 0$ the duty cycle is increased.

This algorithm works in an iterative cycle, where the measured power and duty cycle values are updated at each iteration. In this way, the system dynamically adjusts the duty cycle based on power changes to reach or approach the maximum power point (Maximum Power Point). This algorithm continuously optimizes the duty cycle by detecting power changes, so that the solar panel can operate at maximum efficiency. Unlike the modification algorithm, the conventional algorithm has the disadvantage of being less precise in setting the duty cycle because it only considers power changes ($P(k)$) without considering previous duty cycle changes (ΔD) like the modification algorithm. This can lead to less than optimal control, especially in dynamic operating conditions. In addition, the conventional algorithm has the potential to cause higher oscillations around the maximum power point. The duty cycle can continue to change even though the power is close to the maximum value, which results in system instability. On the other hand, the modification algorithm with more complex logic is able to reduce the potential for such oscillations.

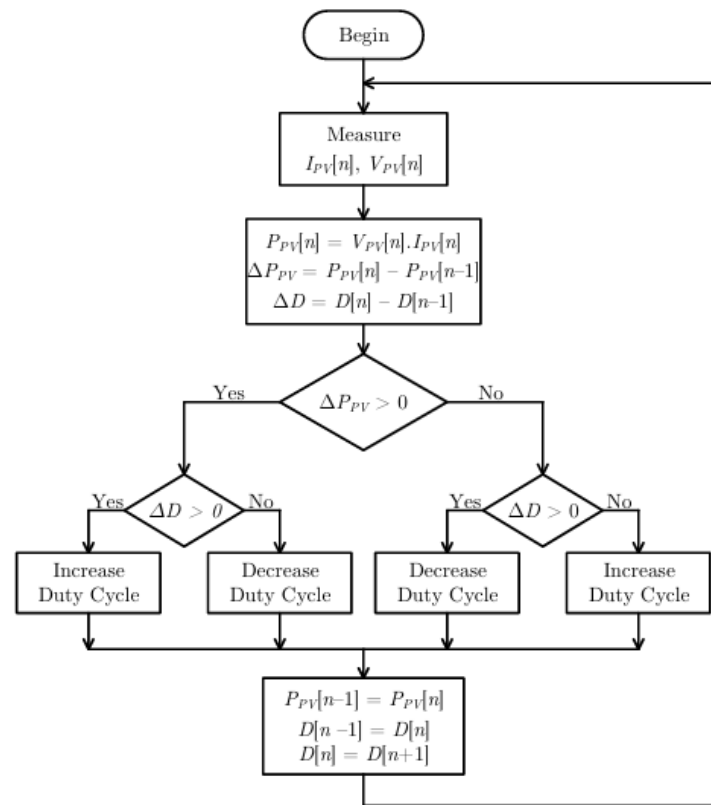


Figure 3. Modified hill climbing algorithm

3. RESULTS AND DISCUSSION

Maximum Power Point Tracking (MPPT) testing using the conventional hill climbing method and modifications to solar panels with boost converters is carried out based on a number of important parameters, such as output voltage (Vout), output current (Iout), output power (Pout), and tracking time required by both methods to reach Maximum Power Point (MPP).

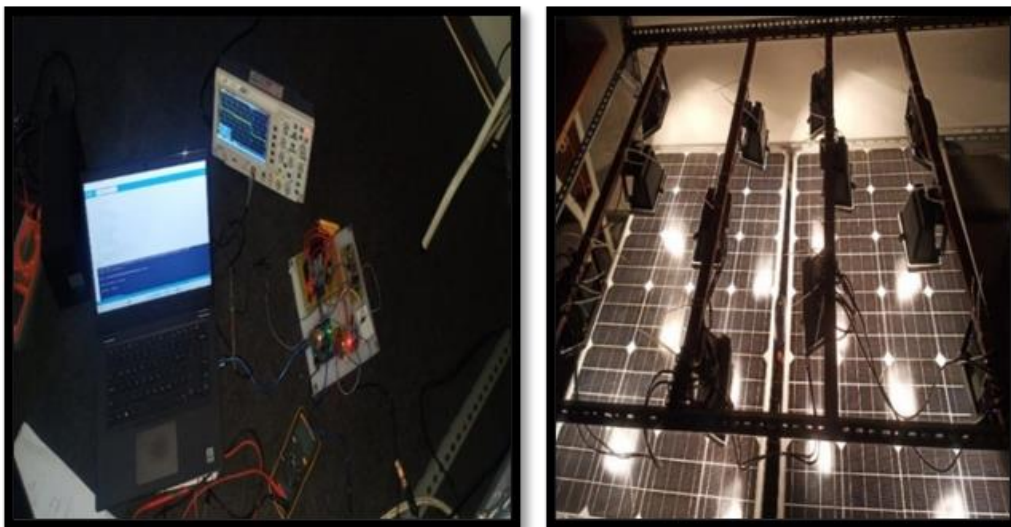


Figure 2. MPPT hill climbing testing

This test was conducted by analyzing the data obtained at various irradiance conditions, ranging from 200 W/m² to 600 W/m², to evaluate the efficiency and tracking speed of the two methods. This system uses a 100 WP solar panel, the output of the solar panel is directly connected to the input of the boost converter. Variations in irradiance on the solar panel were carried out to obtain relevant data, so that the results obtained can provide a clearer picture of the performance and effectiveness of the two MPPT methods in various environmental conditions.

Table 1. Conventional hill climbing algorithm

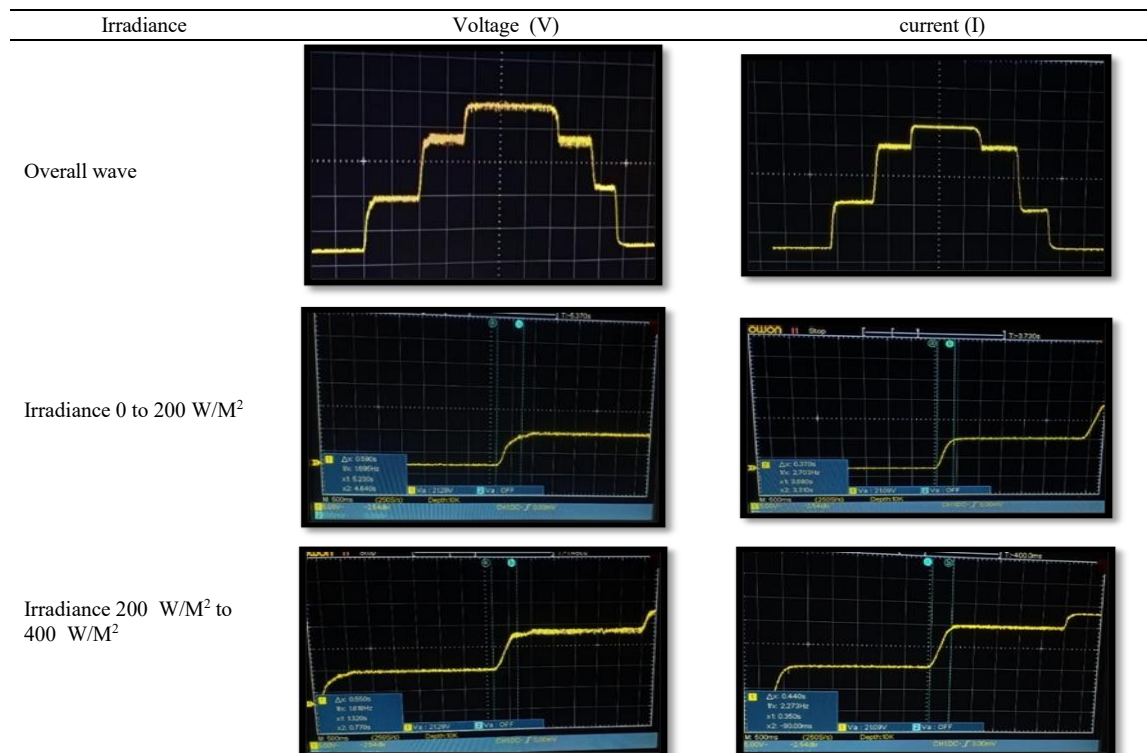
Irradiance	Voltage (V)	current (I)	Power (P)	Tracking Time
200 W/M ²	7.59 V	0.27 A	2 W	590 ms
400 W/M ²	16.7 V	0.43 A	7.18 W	550 ms
600 W/M ²	19.3 V	0.58 A	11.19 W	380 ms
400 W/M ²	16.7 V	0.43 A	7.18 W	370 ms
200 W/M ²	7.59 V	0.27 A	2 W	500 ms

Table 2. Modified hill climbing algorithm

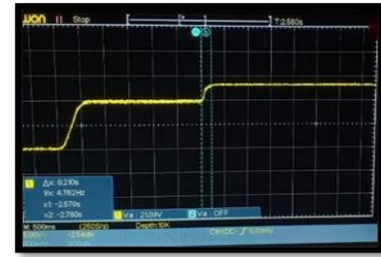
Irradiance	Vout (V)	Iout (I)	Daya (P)	Waktu Pelacakan
200 W/M ²	10.54 V	0.3 A	3.16 W	370 ms
400 W/M ²	17.2 V	0.48 A	8.25 W	440 ms
600 W/M ²	19.8 V	0.66 A	13.12 W	210 ms
400 W/M ²	17.2 V	0.48 A	8.25 W	270 ms
200 W/M ²	10.54 V	0.3 A	3.16 W	460 ms

The evaluation conducted on the conventional and modified methods can be seen in Tables 2 and 3, yielding comprehensive results that include various important data such as output voltage (V_{out}), output current (I_{out}), output power (P_{out}), and the time required to reach the Maximum Power Point (MPP) for each tested MPPT method. The results demonstrate significant differences between the conventional hill climbing method and the modified method, particularly in terms of tracking efficiency and the power obtained by both algorithms. With variations in irradiance from 200 W/m² to 600 W/m², data were collected that detail the system's performance, allowing for an assessment of the effectiveness of both MPPT methods in maximizing power output from the solar panel under dynamic environmental conditions. From the evaluation of the conventional and modified hill climbing MPPT methods, the following waveforms were obtained:

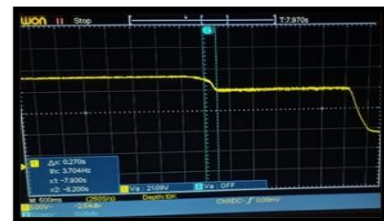
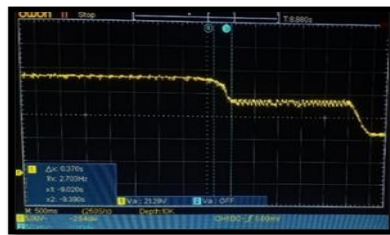
Table 3. Conventional and modified HC MPPT waves



Irradiance 400 W/M² to
600 W/M²



Irradiance 600 W/M² to
400 W/M²



Irradiance 400 W/M²
to 200 W/M²

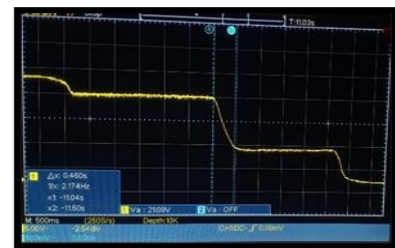
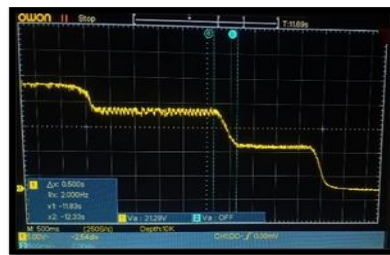


Table 3 shows a comparison between the wave responses of the conventional hill climbing MPPT method and the modified MPPT method. The waveform generated by the conventional MPPT tends to exhibit more oscillations compared to the modified MPPT. These oscillations indicate that the conventional MPPT algorithm experiences greater fluctuations in the process of searching for the Maximum Power Point (MPP), resulting in less stable power output. Additionally, the tracking time required by the conventional MPPT is longer than that of the modified MPPT. This indicates that the conventional algorithm takes a longer time to reach a stable maximum power condition in the solar power system, especially when irradiance changes occur. In contrast, the modified MPPT is able to reduce tracking duration and provide a faster and more stable response in reaching the maximum power point, thereby enhancing the overall efficiency of the solar power system.

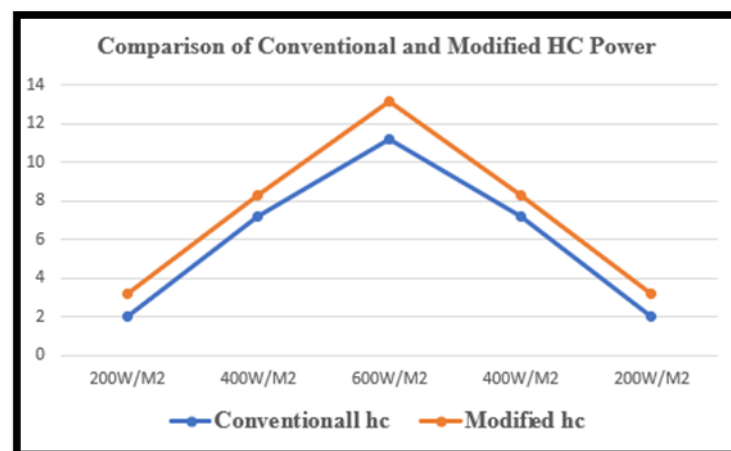


Figure 3. Comparison of conventional and modified hill climbing tracking times

Figure 5 shows a performance comparison between conventional and modified methods in terms of power achievement at various irradiance levels. In the power graph, the modified hill climbing MPPT shows better performance in producing higher power compared to the conventional method. Especially at an intensity of 600 W/m^2 , the modified hill climbing MPPT is able to achieve a peak power of 13.12 W , while the conventional method only reaches around 11.19 W . This indicates that the hill climbing MPPT is more efficient in capturing maximum power at various irradiance levels.

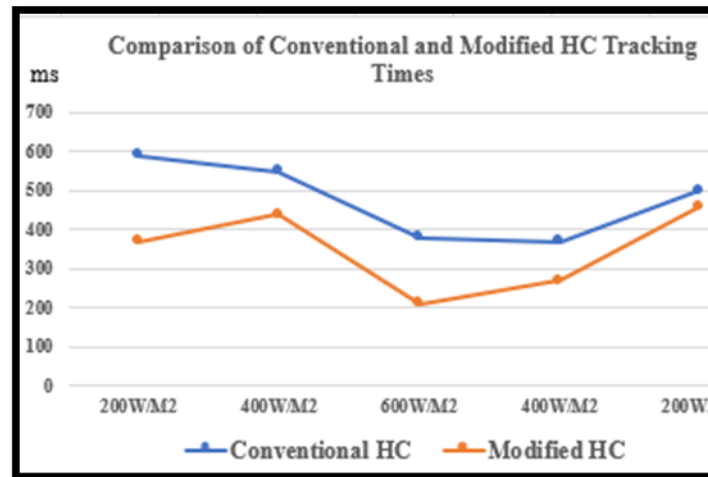


Figure 4. Comparison of Conventional and Modified HC Tracking Times

Figure 6 shows a tracking time graph showing a comparison between the conventional and modified MPPT hill climbing methods in responding to changes in irradiance from 200 W/m^2 to 600 W/m^2 , and vice versa. From the graph, it can be concluded that the modified MPPT hill climbing method consistently requires faster tracking time than the conventional method. At irradiance 0 to 200 W/m^2 , the conventional hill climbing method requires a much longer tracking time of 590 ms , while the modified MPPT hill climbing only requires 370 ms . When the irradiance increases to 600 W/m^2 , the time difference becomes more visible, where MPPT hill climbing records the fastest tracking time of around 210 ms , while the conventional method still requires 380 ms . In addition, when the irradiance drops again, the hill climbing method remains faster in tracking the maximum power point.

4. CONCLUSION

The use of the modified hill climbing MPPT algorithm significantly enhances the efficiency of the system in maximizing power from the solar panel. The time required to reach the maximum power point is faster compared to conventional testing. In the irradiance variations tested using the conventional method, the response showed the presence of ripples or oscillations. This indicates that the conventional hill climbing method is less capable of responding quickly and efficiently to changes in irradiance, resulting in suboptimal power output. To further optimize the hill climbing algorithm for a faster response and to reduce the oscillations, the MPPT hill climbing algorithm can be enhanced. For example, by incorporating more adaptive control strategies that respond better to changes in irradiance.

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