Analysis of Multiple Maximum Power Point Tracker Algorithm with Boost Converter in Photovoltaic System

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Abstract

This paper addresses the global need for increased energy efficiency in photovoltaic (PV) power generation through Maximum Power Point Tracking (MPPT) techniques—specifically Perturb and Observe (P&O) and Incremental Conductance (INC) integrated with a boost converter. The work focuses on improving PV system performance, facing challenges like low conversion efficiency and variable power generation. Objectives include creating a basic PV system, simulating P&O and INC algorithms in MATLAB Simulink, coding for Arduino, and assessing their performance under varying irradiance and temperature. The work utilizes a boost converter, MATLAB Simulink for simulation, and specific PV panel parameters which is 20W, 17V and 1.18A for each panel. It contributes insights into the comparative analysis of P&O and INC algorithms for optimizing PV system efficiency. Three PV panels is used for hardware and six PV panels is used in the simulation works. Arduino Mega 2560 is used as Pulse Width Modulation (PWM) generator in hardware implementation. The load used for simulation is 170Ω while load used for hardware is 88Ω. The results present a thorough study of PV system performance under changing conditions, showing that both algorithms effectively regulate voltage and current, though INC demonstrates a slight advantage in certain aspects. Hardware experiments yield promising results for both MPPT algorithms, with efficiency dropping under low irradiance conditions. It can be hard to compare because of the limitation of components available. This paper provides valuable insights into MPPT algorithm performance, emphasizing their strengths and limitations in different environmental conditions.

1. Introduction

The global demand for energy consumption is rapidly increasing in this modern era. It moves along with the development of modern technology and machines that mostly depend on electrical energy. As opposed to other renewable energy resources, PV power generation throughout the world is becoming increasingly popular due to combination factors such as low maintenance, minimal wear, and tear of components due to absence of moving parts, absence of fuel cost. However, PV systems have two major problems which are related to low conversion efficiency especially in low irradiation conditions and the amount of electric power generated by PV arrays varies continuously with weather conditions [1]. Therefore, many research works are done to increase the efficiency of

the energy produced from the PV arrays. Hence, multiple techniques have been developed to overcome the limitations of the energy conversion from the solar panel. One of the techniques is the MPPT.

MPPT is a technique used in power electronic circuits to extract maximum energy from the PV systems. The MPPT is important to make sure the PV systems always operate at the maximum power point to improve the energy efficiency of the PV system. According to the study from Indonesian Journal of Electrical Engineering and Computer Science, the comprehensive commonly used MPPT techniques which are P&O, INC, and Hill Climb [2]. These techniques are different from each other by their cost, complexity, benefits, and drawbacks. In this paper, the most popular two techniques, which are P&O and INC is examined with the connection with a boost converter.

The inconsistency of the PV systems output leads to the studies on the MPPT algorithm development. These studies mostly solve inconsistency issues and reduce the cost while improving the efficiency of the PV systems. The proposed idea for this study is to compare the efficiency when the P&O algorithm and INC algorithm is used in the MPPT charge controller.

2. Materials and Methods

The system in this work is an MPP controller for the PV system by using two different MPPT algorithms which are P&O and INC. The block diagram in Fig. 1 shows the overall process of the MPP controller for the PV system. The system is start with the solar panel receiving input from the irradiance and temperature. From the input, the power input can be obtained as the voltage and current is measured. As this system is targeted to find the difference between P&O and INC algorithms in handling the changes of the voltage and current input for the PV system, those algorithms will use the coding in the Arduino Mega 2560 to calculate the duty cycle each time the voltage and current is change. After that, the input value of the voltage and current will flow through the boost converter to step up the voltage output. Lastly, the power, voltage and current output are recorded and analyzed to make a comparison between the P&O and INC algorithms.
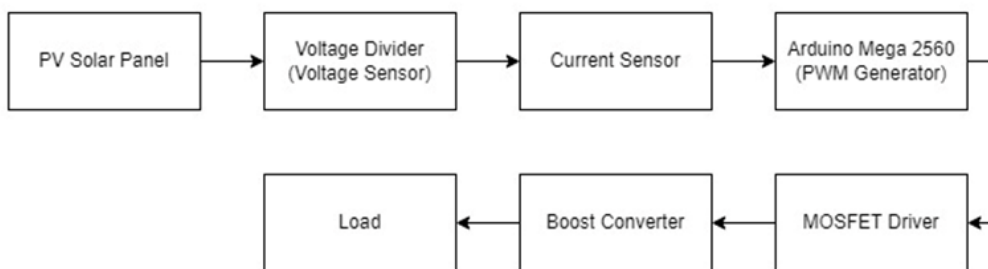

Fig. 1 *System Block Diagram*

2.1 PV Panel Parameter

Table 1 shows the parameters of the PV panel that was used for this work.

Table 1 *Parameter of the PV Panel*

Description	Parameter Value
Number of cells	36
Maximum power	20W
Voltage open circuit	22V
Current short circuit	1.32A
Voltage at MPP	17V
Current at MPP	1.18A

2.2 Maximum Power Point Tracker Algorithm

To design both MPPT in the MATLAB, the behavior and concept used by both methods in tracking the maximum power need to be understood first.

2.2.1 Perturb and Observe

As shown in Fig. 2 (a), the voltage and current from the panel are measured to get the input power. Next, the changing of power (dP) and perturbation of voltage (dV) by a small magnitude is observed. Until there is no longer any increase in power, adjustments are made in the same way. Should the dP be smaller than zero, the perturbation direction needs to be reversed for the working point to go back towards the mean perturbation point. Fig. 2 (b) shows the algorithm coding in the MATLAB Simulink [3].
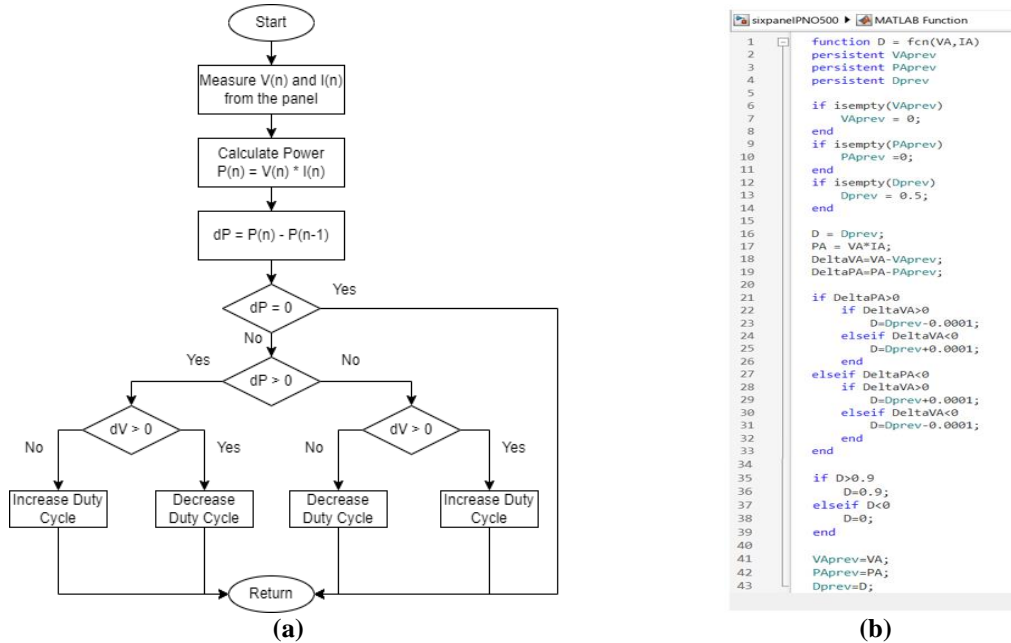

| (a) | (b) |

Fig. 2 (a) *Perturb & Observe Algorithm; (b) Perturb & Observe MATLAB Code*

2.2.2 Incremental Conductance

As shown in Fig. 3 (a), the PV array's change in current (dI) divided by change in voltage (dV), is calculated by the INC method. Additionally, it compares the current-voltage (I-V) changes at the present operating point to determine the incremental conductance. The slope of the tangent to the power-voltage (P-V) curve is represented by the INC. Fig. 3 (b) shows the algorithm coding in the MATLAB Simulink [4].
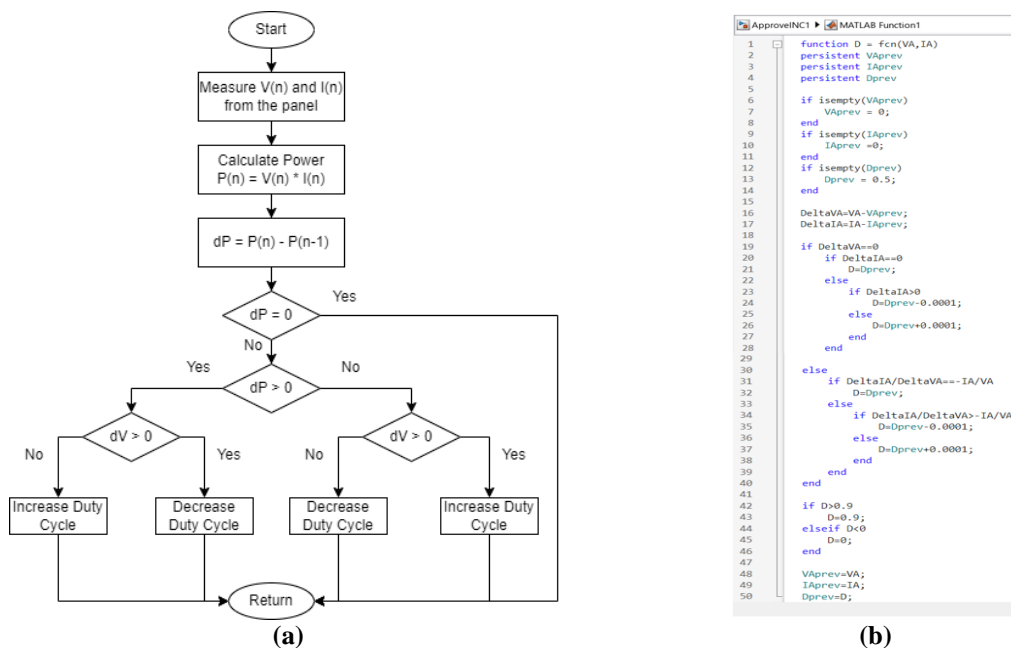

| (a) | (b) |

Fig. 3 (a) *Incremental Conductance Algorithm; (b) Incremental Conductance MATLAB Code*

2.3 Boost Converter

This work uses a unique boost converter, which differs slightly from standard ones. As shown in eq. (1) and eq. (2), Cin and Cout are two unique capacitors that are part of it. Cin assists in ensuring that the voltage and current of the electricity remain constant and do not fluctuate excessively. It functions as the solar power system's helpful companion, keeping everything running smoothly. Cout, the other capacitor, functions as an electrical storage tank. It ensures that the power remains steady and doesn't fluctuate by storing excess energy during the process and releasing it when needed. Together, these two capacitors enable the boost converter for solar panels to function well, ensuring that users receive a reliable and consistent supply of solar power to meet their needs.

Capacitor input (Cin):

$$Cin = \frac{4 \; x \; Vmp \; (normal \; condition) \; x \; Dmp \; (normal \; condition)}{\Delta Vin \; x \; Rin \; x \; Frequency} \tag{1}$$

Capacitor output (Cout):

$$Cout = \frac{2 \; x \; Vout \; (worst \; condition) \; x \; Dmp \; (normal \; condition)}{\Delta Vin \; x \; Rin \; x \; Frequency} \tag{2}$$

Inductor (L):

$$L = \frac{Vmp \; (worst \; condition) \; x \; Dmp \; (worst \; condition)}{2 \; x \; \Delta Iout \; x \; Frequency} \tag{3}$$

The boost converter modelling is referred to the previous boost converter calculation and calculated again to use for the three-panel setup. The component that was used in the boost converter is tabulated in Table 2.

Table 2 *Component value for boost converter*

Component	Value
Capacitor Input	78μF
Capacitor Output	36.5μF
Fuses	3A
Inductor	0.287mH
Resistor (Load)	88Ω

## 2.4 Hardware Setup

2.4.1 PV Panel Configuration

The setup for the PV system for hardware setup is separated into two sections. Six solar panels were used in this work. The first three panels that are connected in series was linked directly to the load for the first section. The second section where three panels was connected in series with the additional connection to MPPT controller and boost converter. To guarantee that the solar PV panels receive the maximum amount of irradiance, this arrangement is mounted on an iron frame with adjustable angle positions. In terms of system division, the setup is in a vertical position. The system for the upper three PV solar panels incorporates the MPPT system, while the lower three PV solar panels do not utilize the MPPT system. The PV solar panel configuration is shown in Fig. 4.

Fig. 4 *PV solar panel configuration*

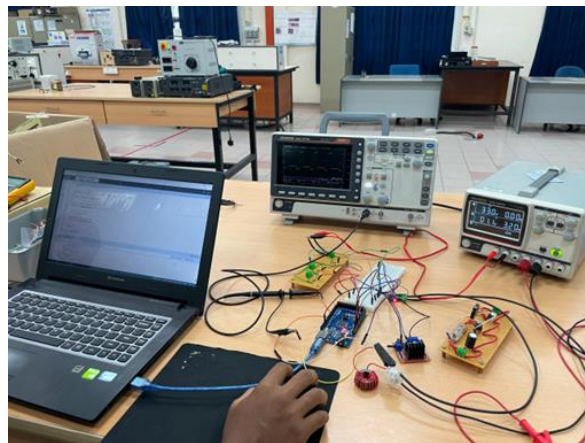## 2.4.2 Boost Converter and MPPT Controller Configuration

The ARDUINO microcontroller, which functions as an MPPT, is used for the boost converter and MPPT controller setup. The ARDUINO MEGA board controller is programmed with the P&O and INC algorithms for MPPT coding. The job of this microcontroller is to compute the voltage and current to ascertain the power generated by the photovoltaic panel and, in turn, to determine the duty cycle value that the boost converter requires. The MPPT controller and boost converter arrangement tested in the lab is shown in Fig. 5. The setup includes the voltage divider, ACS712 current sensor module, and L298N dc motor driver for controlling pulse width modulation that will be supplied to MOSFET.
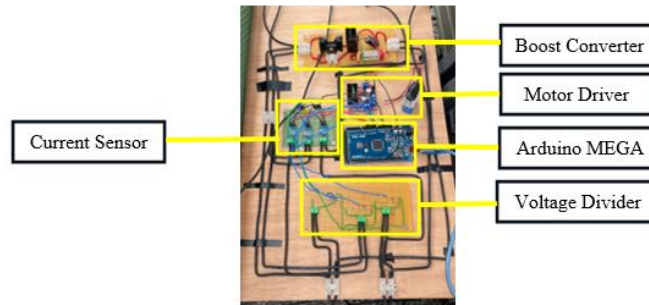
Fig. 5 *Boost Converter and MPPT Controller Configuration*

2.4.3 Boost Converter and MPPT Controller Test and Setting

It is crucial to calibrate the MPPT controller and boost converter before mounting them on the PV panel. Since the voltage and current readings are essential for calculating the duty cycle value, this calibration guarantees that the readings reach accurate values.

The purpose of this testing phase is to evaluate the boost converter's durability. Verifying that the boost converter can tolerate the voltage and current produced by the PV solar panel is the main goal. An oscilloscope is used to view the PWM signal, as shown in Fig. 6. They also make use of a DC power supply to supply voltage and current in compliance with the PV solar panel's specs.

Fig. 6 *Boost Converter and MPPT Controller Test and Setting*

3. Result and Discussion

The comparison of output between two types of MPPT algorithms which P&O and INC can be proven in this chapter. The irradiance and temperature changes were recorded. Case 1 is the solar irradiance variation and Case 2 is the temperature variation. Fig. 7 shows the simulation circuit in the MATLAB Simulink.
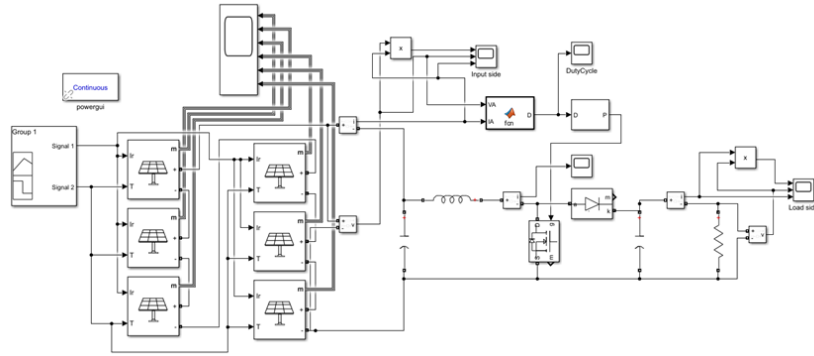
Fig. 7 *Simulation circuit in MATLAB Simulink*

3.1 Case Studies

In the case of study 1, researchers conducted a simulation under a variation of irradiance as shown in Fig. 8 (a). This profile is not very realistic, but it will be equivalent to a very fast cloudy day and allow giving a thought of measure of how speed the controller responds. For the second case study, the irradiance will stay but the temperature will vary at a certain time for all panel like shown in Fig. 8 (b).
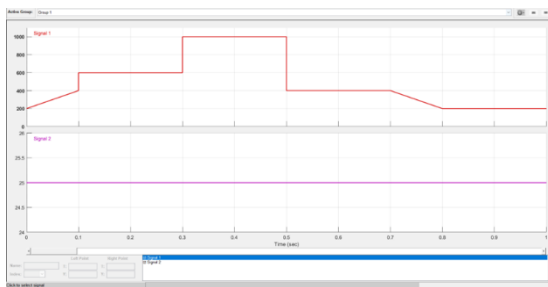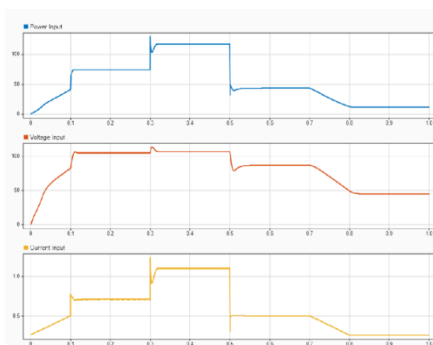

(a)
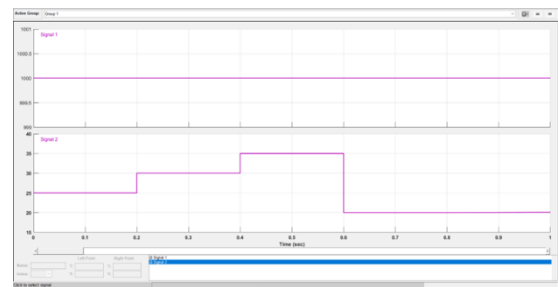
(b)

Fig. 8 *(a) Irradiance variation profile; (b) Temperature variation profile*

3.2 Simulation with P&O algorithm

3.2.1 Case Study 1

Researchers found that the PV system's power production stays the same for the input and output after examining the output graphs shown in Fig. 9 (a) and (b). Nonetheless, the boost converter and MPPT controller efficiently control the changes in voltage and current by controlling the duty cycle.

(a)

(b)

Fig. 9 *(a) Power, voltage, and current input; (b) Power, voltage, and current output*

3.2.2 Case Study 2

Fig. 10 (a) and (b), show that there will not be much difference between the variation of temperature that can impact the power, voltage, and current value.

(a)   **(b)**

Fig. 10 *(a) Power, voltage, and current input; (b) Power, voltage, and current output*
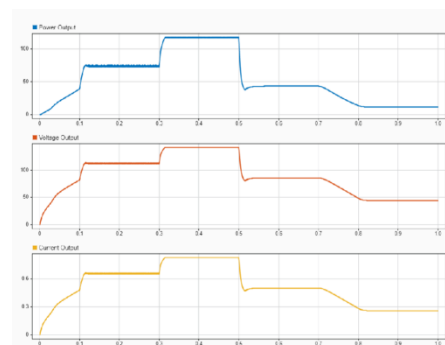
3.3 Simulation with INC algorithm

3.3.1 Case Study 1

Researchers found that the PV system's power production stays the same for the input and output after examining the output graphs shown in Fig. 11 (a) and (b). Nonetheless, the boost converter and MPPT controller efficiently control the changes in voltage and current by controlling the duty cycle.

(a)   **(b)**

Fig. 11 *(a) Power, voltage, and current input; (b) Power, voltage, and current output*

3.3.2 Case Study 2

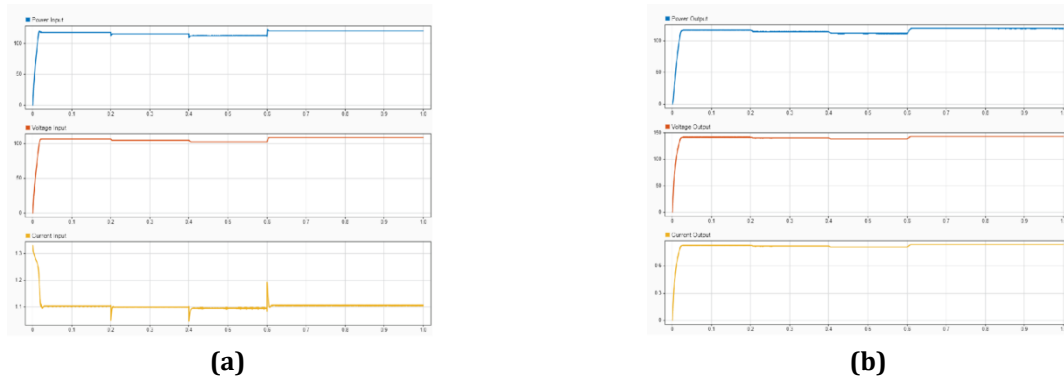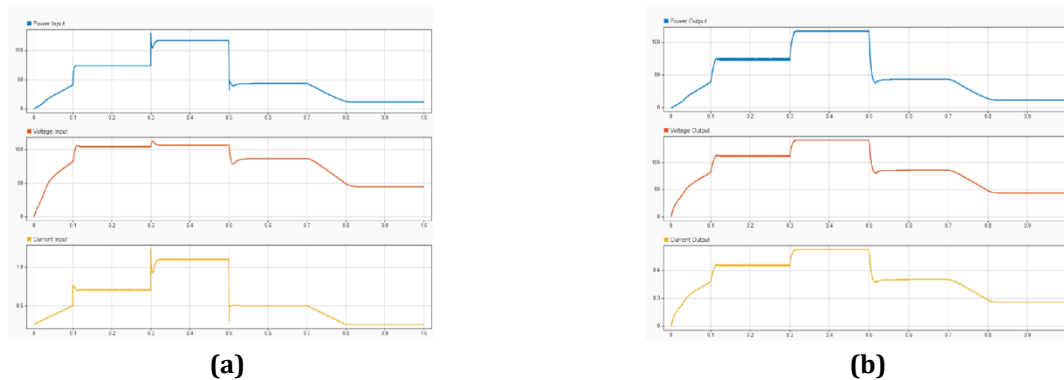Fig. 12 (a) and (b), show that there will be not much difference between the variation of temperature that can impact the power, voltage, and current value. The difference between INC and P&O can be seen in the ripple of the current.

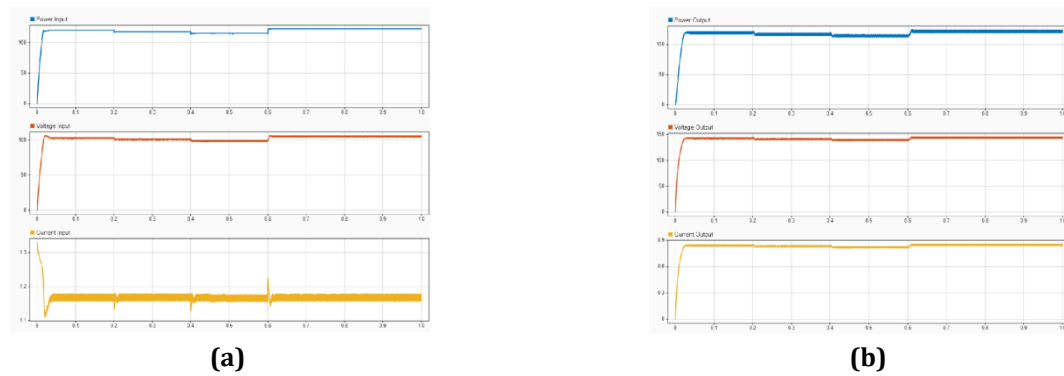**(a)**   **(b)**

Fig. 12 *(a) Power, voltage, and current input; (b) Power, voltage, and current output*

3.4 Data Analysis of Simulation

Based on Table 3, the efficiency of both algorithms does not have much difference even on the irradiance variation. The efficiency will be close as much as 98%-100% to the theoretical power from the PV when the irradiance at

800 W/m² and 1000 W/m². The efficiency will decrease significantly when the irradiance is low. At 400 W/m² the efficiency for both algorithms can catch up to 87% and at 200 W/m² it will decrease more than half which is the efficiency only up to 46.6% for both algorithms.

Table 3 *MPPT efficiency under variation irradiance*

Irradiance (W/m²)		1000	600	400	200
Power from PV curve (W)		120.36	74.62	50.20	25
P&O MPPT	Power (W)	118	74.58	43.75	11.65
	Efficiency	98%	99.9%	87.15%	46.6%
INC MPPT	Power (W)	118	74.62	43.77	11.65
	Efficiency	98%	100%	87.19%	46.6%

Table 4 shows the efficiency of both algorithms when the temperature is varied. For the INC algorithm, the efficiency will get the maximum efficiency same as the theoretical power from the PV. But for P&O algorithm, the efficiency will only get on the range of 97%-98%. Even if there is only a small difference in value, we can conclude that INC algorithm is much more efficient than P&O when the temperature is varied.

Table 4 *MPPT efficiency under variation irradiance*

Temperature (°C)		20	25	30	35
Power from PV curve (W)		122.798	120.36	117.901	115.427
P&O MPPT	Power (W)	120.5	117.8	115.3	112.6
	Efficiency	98.13%	97.87%	97.79%	97.55%
INC MPPT	Power (W)	122.8	120.3	117.9	115.4
	Efficiency	100%	100%	100%	100%

3.5 Data Analysis of Hardware Implementation

The hardware experiment will be divided into two sections. First, operate two systems simultaneously and compare the differences between the systems that use the P&O MPPT controller and the ones that do not. Secondly, run two systems simultaneously and compare the differences between the systems that use the INC MPPT controller and the ones that do not. To allow for an appropriate comparison, this experiment also makes sure that each system receives the same amount of irradiance. The outcome for both sections shown in Table 5 and Table 6.

Table 5 *Result hardware with P&O algorithm*

Record Time	Irradiance (W/m^2)	Voltage Input (V)	Voltage Output (V)
11 a.m.	824	22	42
12 p.m.	675	38	48
1 p.m.	626	28	40

Table 6 *Result hardware with INC algorithm*

Record Time	Irradiance (W/m^2)	Voltage Input (V)	Voltage Output (V)
11 a.m.	861	45	57
12 p.m.	830	46	56
1 p.m.	698	41	45

4. Conclusion

In conclusion, this research is focused on findings the difference between two types of MPPT algorithms. The study case developed is important to observe the changes of MPP in the PV system when the irradiance and temperature

is varied. The effectiveness of this approach was validated through the simulation and hardware. The circuit used for simulation and hardware can run normally to get the result of the power. The algorithm used for simulation and hardware is quite different because it used different platforms, but the flow is still the same. For the coding, it may need future improvements to make sure it can be run perfectly for the hardware implementation.

Based on the results from the simulation, there is not much difference between those two algorithms. The efficiency of those algorithms is quite similar because both algorithms still use the voltage and current value to calculate the maximum power of the system. When the irradiance varies, the efficiency has a range from 46%-100%. The difference can be observed from the ripple of the voltage, current and duty cycle where the INC have much more ripple in finding the MPP compared to P&O. For the hardware, it can be hard to compare because of the limitation of components available.

Acknowledgement

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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