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Maximum Power Point Tracking Using Perturb and Observe Technique

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Abstract: The research on Maximum Power Point Tracking (MPPT) using Perturb and Observe (P&O) is conducted to observe the behavior of the I-V curve output from the PV cell. The MPPT will track the maximum power point using the P&O algorithm. The P&O is widely known for its simple implementation on the PV system. The P&O method will enhance the efficiency of the PV cell. The P&O algorithm is designed using MATLAB coding (mfile). The mfile can be inserted in the circuit design in the Simulink. Simulink is used to design the PV circuit. The PV connected to P&O algorithm is tested under multiple condition. The outcome of this analysis is the maximum power point (PMP), voltage at maximum power point (VMPP) and current at maximum power point (IMPP). From there, the characteristics of the PV module can be study. The P&O output is than compared with the datasheet where for this research uses Soltech 1STH-215-P. This is to obtain the efficiency of P&O algorithm.

Keywords: Photovoltaic (PV) Model, MATLAB Simulink, Soltech 1STH-215-P

1.0 INTRODUCTION

Electrical energy generation is very intense in a country as it needs to meet the high demands of the country to support the domestic activity such as homes, school, and factories. In these modern days, many countries use renewable energy to overcome the problem when using finite resources such as petroleum, fossil fuel and natural gas which will run out in our lifetime. Renewable energy is energy extracted from normal, regular, and continuous energy flows that exist in the local environment [1]. Despite having unlimited resources, other advantages of using renewable energy are it is eco-friendly.

Thus, to solve this problem, the output efficiency of PV array can be increased by operating the PV energy sys One of the common renewable energies used is solar energy. Solar 1ways, either by thermal route or photovoltaic conversion by using solar cell [2]. Although solar is famous for its cost-effective and simple system design, there is also problem in generating the energy where the amount of energy produces depends on the sunlight produces which is different depends on the geographical location and climate changes. This research, it will study the solar maximum power point tracking (MPPT) technique used to optimize the solar energy generation which is used to increase the efficiency of the PV system. The maximum power point tracking will trace the maximum power point on the PV module characteristic curve and the charge controller will regulate the voltage and current to the desired values [3].

The research studies on the Perturb and Observe (P&O) technique which is the algorithm used for the maximum power point tracking. The actual value of the PV output power is calculated in this technique and compared with the past value which gives the power difference. If the power exceeds zero, the same action proceeds for some further perturbation or else it moves in the opposite direction. Hence, country which has low amount of sun insolation may practice this solar MPPT using P&O technique as it is easy to be implemented and further increase the efficiency of the solar PV cell.

2.0 LITERATURE REVIEW

A photovoltaic (PV) cell unit is defined as power semiconductor devices which converts light energy to electrical energy though PV effect condition. The performance of a PV system depends primarily on the availability of solar radiation and the performance of conversion; many physical parameters such as site latitude, standard weather conditions, panel tilt and azimuth angles, air and surfaces around temperatures, and eventually electrical loads affect these important characteristics.

The efficiency of the PV cell depends on various ambient condition. These factors should be considered as it gives significant impacts to the cell output in real application [4]. MMPT device is required to extract the highest power from the system. During hot sunny condition, it can extract power normally but during shading, it is unable to extract maximum because it unable to track maximum power. This is because the system obtains multiple reading of the peak at the solar output [4].

Irradiance gives the definition of the measured of power density of sunlight density obtained at a location which is measured in watts per metre square [5]. The Si unit of irradiance is Watt per square meter (Wm-1). The irradiance gives effect to the open circuit voltage of the PV panel. The open circuit voltage is directly proportional towards solar radiation as the short current increase linearly [6]. The PV characteristic can be seen in the graph which shown at Figure 1.

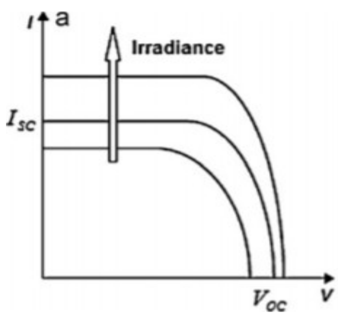

Figure 1 Effect of increased radiance

The temperature of the module is a parameter that has a huge impact on the behavior of a PV system, as it modifies the efficiency of the system and the output energy. The voltage produce by the PV cell is inversely proportional towards the temperature. Higher voltage will be produced when the temperature drops and vice versa.

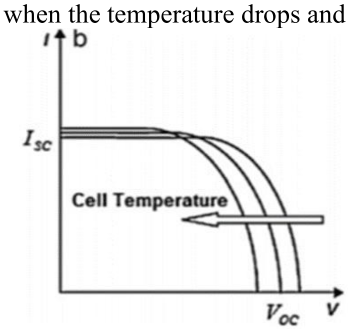

Figure 2 Effect of increased temperature

The temperature gives effect to the band gap of the semiconductor in the PV cell. When there is an increase in temperature, the semiconductor's band gap will shrink thus decreases the open circuit voltage (V_{oc}) due to the p-n junction temperature voltage dependency in the diode factor (q/kT). This will result in negative temperature coefficient of V_{oc} in the PV cell [6]. Based onthe PV graph in Figure 2, it shows the effects of cell temperature on the PV cell characteristics. As the cell temperature increases, the open circuit voltage will drop linearly with the cell temperature and also decreases the cell efficiency. In the literature, cooling the module and reducing the PV cell's heat stored within it during can improve the efficiency and decrease the rate of thermal degradation of the PV module.

In a PV system, developing the correct model which suit the system is important to simulate and foresee the behavior of PV modules, especially when designing, producing, and evaluating a largescale PV system. [7] These models of electrical circuits are used to define PV characteristic curves for I-V and P-V module for precise production, operation, and accuracy discover the causes of PV output loss. [8] Based on the past research that have been made, by following the single- diode model (SDM) and the double-diode model (DDM), several researchers have built PV cells and modules by applying the single-diode model (SDM) and the double- diode model (DDM). The SDM model as shown in Figure3 is widely known for its simplicity, accuracy, and low cost but since the losses from recombination are not taken intoconsideration, at low solar irradiation amounts, its precision at open-circuit voltage (OCV) decreases greatly. In other to improve the modelling accuracy, the DDM PV module is used by connecting another diode in parallel with the SDM.[9]

The SDM shows serious short-coming when it is subjected to the change of temperature and worsen its accuracy at low radiator level. [8] So for this research, the design of DDM such as in Figure 4 the as the PV model because recombination is a significant loss in a real solar cell, which cannot be accurately modelled on a SDM. In the DDM design, an additional diode (D2) in parallel of D1. The accuracy of the PV cell can be increase through this proposed model and can overcome short-coming of SDM.

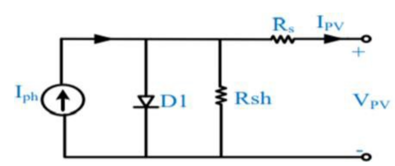

Figure 3 Equivalent Single Diode Model Circuit

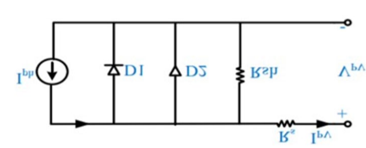

Figure 4 Equivalent Double Diode Model Circuit

MPPT is the algorithm used in the charge controllers which is used to obtain the maximum usable power from the PV module under some conditions. The voltage at which maximum power can be produced by the PV module is called the maximum power point (or peak power voltage). Maximum power varies in terms of solar radiation, atmospheric temperature, and temperature of solar cells. Solar PV system is a good power generation solution for sustainable energy but due to the factors mentioned above, the power generation can significantly fluctuate. [6] Solar irradiance, which is an integral factorin PV power output fluctuation and losses, is not strongly correlated between near locations over a limited timescale. [10] So, MPPT method is the solution to increase the PV system efficiency. Solar irradiation and temperature levels plays important role in attaining maximum power from the PV system through MPPT method. However, the PV system efficiency can be negatively affected due to the non-steady characteristics of the irradiance and temperature variation.

Maximum power transfer theory tells that when the source impedance is equal to the load impedance where it is called load matching, the maximum power will be transferred from the source to load. By adjusting the duty cycle of the DC-DC converter, the load matching can be achieved. The ratio of the duty cycle is between the switching on time to the switching period. When the converter is operated by the duty cycle corresponding to it, the maximum power point can be track. [11] From the literature, there are three types of converters that is commonly used in the PV system application which is boost converter that is use to step up input voltage, buck converter which functions to step down the input voltage and buck-boost converter which is the combination of both boost and buck converter. [12]

3.0 METHODOLOGY

In this section, it will discuss all the method used to conduct the research on MPPT technique using perturb and observe technique. This chapter will discuss the technique used in MPPT to track the maximum power point, the expected outcome from this analysis and also discuss on how the data obtain from this research is evaluated. It will also discuss regarding on how data irradiance and temperature data are predicted and elaborate on the model used in the PV cell. The flowchart of the P&O algorithm is also included in this chapter.

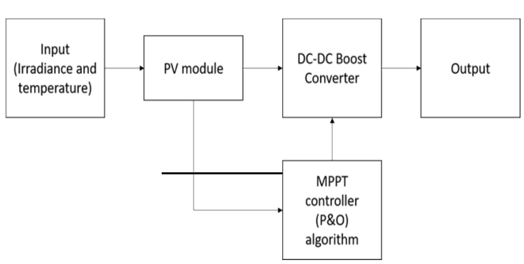

Figure 5 Block diagram of the PV module with P&O MPPT Technique

Figure 5 illustrates a block diagram of the PV cell implemented with MPPT controller. The PV cell will receive input consists of irradiance and temperature. Then the PV cell will generate output voltage. To regulate the voltage produced by the PV cell, MPPT controller is used. MPPT controller will harvest the maximum power from the PV cell by comparing the input voltage with the V_{mp}.

The MPPT controller will track the maximum power point of the PV cell by using P&O algorithm. The MPPT will then generate a PWM signal and send it to the IGBT MOSFET at the DC-DC Boost Converter. MOSFET will do a switching process to modify the voltage to obtain P_{MPP}. The P_{MPP} will be studied to evaluate the performance of the PV module.

This research implements SDM PV model. The SDM has lower capability to achieve maximum power compared to DDM. So, this model is suitable in this research to analyze the P&O algorithm in increasing the solar cell accuracy. The design of SDM circuit can be seen in Figure 6. The current source is connected in parallel to a diode. The photocurrent (I_{ph}) produce by the current source is directly proportional to the light falling on the cell. The current flow through the diode is called diode saturation current where it plays an important role in determine the I-V characteristics of the cell.

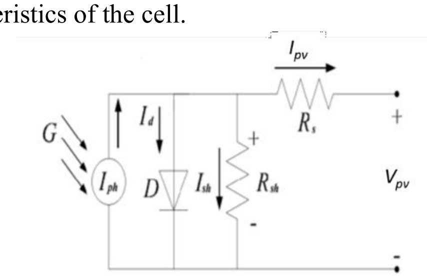

Figure 6 Single Diode PV Model Circuit

The main equation of the SDM is shown in equation 1;

$$I_{pv} = I_{ph}N_p - I_d - I_{sh} \quad (1)$$

The value of I_d, I_s, I_{rs}, I_{sh} and I_{ph} can be obtainedusing equation 2, 3, 4, 5 and 6 respectively.

$$I_d = I_s N_p \left(e^{\frac{(V_{pv} + IR_s)}{(nV_T N_{cell} N_s)}} - 1 \right) \quad (2)$$

$$I_s = I_{rs} \left(\frac{T}{T_{ref}}\right)^3 e^{\left[\frac{qE_g}{nk}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]} \quad (3)$$

$$I_{rs} = \frac{I_{sc}}{\left[e^{\left(\frac{V_{oc}q}{kN_{cell}Tn}\right)} - 1\right]} \quad (4)$$

$$I_{sh} = \frac{V_{pv} + IR_s}{R_p} \quad (5)$$

$$I_{ph} = G[I_{sc} + k_I(T - T_{ref})] \quad (6)$$

DC-DC boost converter as shown in Figure 7 is used to regulate V_{pv} where it will step up the voltage according to the duty cycle (D) received from the MPPT. The inductor (L), diode (D), capacitor (C), load resistor (RL), and control switch make up the DC-DC boost converter circuit (S).

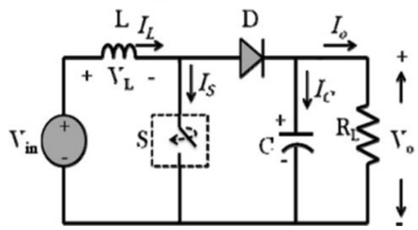

Figure 7 DC-DC Boost Converter

The value of component in DC-DC boost converter can be estimated using equation 7, 8, 9, 10 and 11

$$\frac{V_0}{V_{in}} = \frac{1}{(1-D)} \quad (7)$$

$$L = \frac{V_{in}}{(f_s \triangle I_L)} D \quad (8)$$

$$\frac{\triangle I_L}{I_0} = 0.3 \quad (9)$$

$$C = \frac{I_0}{f_s \triangle V_0} D \quad (10)$$

$$\frac{\triangle V_0}{V_0} = 5\% \quad (11)$$

The method that will be used in the MPPT controller to regulate the solar PV output is P&O algorithm. The P&O algorithm is known for its simple implementation and good excellent tracking efficiency. This analysis will study the behavior of the PV I-V curve when the MPPT P&O algorithm is used. Through this P&O method, the MPPT controller will observe the PV output power and it will perturb the PV output power either increment or decrement depends on the increment of PV voltage or current. This method will compare the present value of the PV output power that was calculated with the past value which will gives the differences in power. The algorithm will continue to perturb the PV operating voltage by a small increment. If the changes in power (ΔP) value is positive, it will move towards the direction of maximum power point and the operating voltage will continue to be perturb in the same direction. If the result of the perturb process leads to negative in ΔP.It will move away from the maximum power point and thesign of the perturbation is changed.

There are several techniques and algorithms, as already stated in the introduction, that allow the idea of tracking the MPP to be implemented. The so-called Perturb and Observe (P&O) that is proposed is one of them. The Figure 8 shows the flowchart of the P&O algorithm operation.

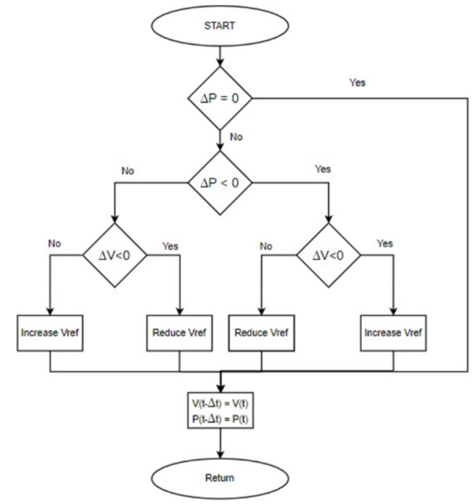

Figure 8 Perturb and Observe (P&O) flowchart

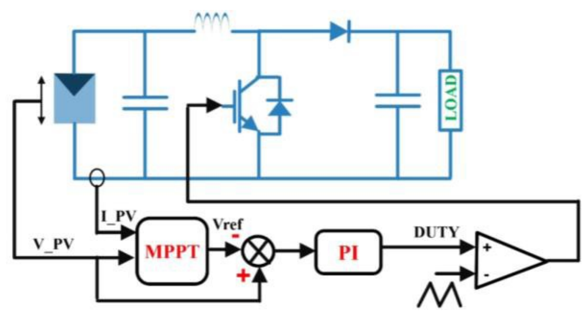

Figure 9 MPPT circuit design

Figure 9 shows the P&O algorithm implemented with analog block. The circuit is design using MATLAB Simulink. This circuit will be designed in the MPPT block. The MPPT will extract the V_{ref} and compare it with V_{pv} and the PI controller will convert it into duty cycle. The duty cycle is the converted to PWM and is sent to the DC-DC boost converter.

4.0 RESULTS AND DISCUSSION

Case study 1 simulates the PV module under different irradiance from G=200W/m2 until G=1000W/m2 at constant temperature 25˚C and under constant irradiance different temperature from 0˚C until 75˚C. The PV module is then connected to the MPPT P&O algorithm and is tested under STC condition. Figure 10, 11 and 12 shows the power, voltage, and current output at maximum power point of the simulation respectively. Meanwhile, Table 1 shows the comparison between the PV output and P&O output against Solarex MSX-60 to obtain the efficiency of the P&O. The datasheet of Solarex MSX-60 is shown in Table 2.

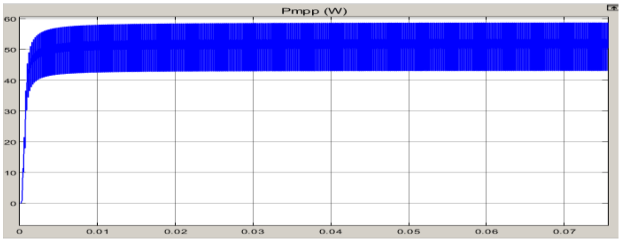
Figure 10 Power Maximum Power Point

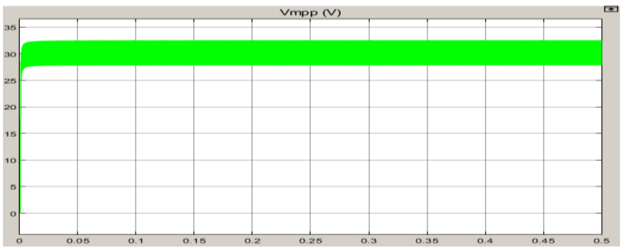
Figure 11 Voltage output of PV with P&O

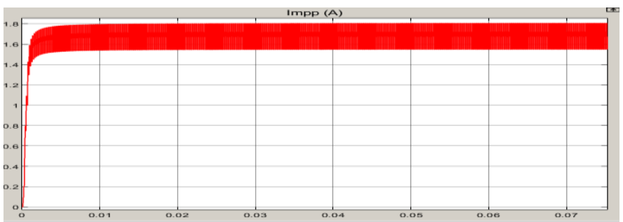
Figure 12 Current output of PV with P&O

Measurement	PV output	PV with P&O output	% deviation
Maximum PowerPoint, P_{mpp} (W)	59.39	58.82	0.959
Voltage at maximum powerpoint, V_{mpp} (V)	16.65	32.54	-95.43
Current at maximum power point, I_{mpp} (A)	3.57	1.81	49.29
Efficiency η (%)	98.98	98.03	0.959

Table 1 Comparison between PV ouput and P&O output

Parameters	Specification
Maximum power (P_{max})	60W
Voltage at Pmax (V_{mp})	17.1V
Current at Pmax (I_{mp})	3.5A
Short Circuit Current (I_{sc})	3.8A
Open Circuit Voltage (V_{oc})	21.1V
Temperature coefficient of open circuit voltage (Kv)	-80mV/˚C
Temperature coefficient of short circuit current (Ki)	0.065%/˚C

Table 2 Solarex MSX-60 datasheet

PV Module specification		Boost DC/DC converter specification	
PV model	1STH-215-P	L1	4mH
Short circuit current (Isc)	7.84 A	C1	100μF
Open circuit voltage (Voc)	36.3 V	C2	100μF
Maximum Voltage (Vmpp)	29 V	R0	20 Ω
Maximum Current (Impp)	7.35 A	-	-
Maximum power (Pmpp)	213.15 W	-	-
Num of cells in series (Ns)	60	-	-
Temperature coefficient of Isc	- 0.36099%/ ˚C	-	-
Temperature coefficient of Voc	0.102%/˚C	-	-
Diode ideality factor (A)	0.98117	-	-
Series resistance (Rs)	0.39383 Ω	-	-
Shunt resistance (Rsh)	313.3991 Ω	-	-

Table 3 PV and DC-DC boost converter parameter

For case study 2, the PV module connected with the P&O algorithm is studied under the partial shading condition which is under varying insolation at constant temperature of 25˚C, under constant insolation 1000W/m^2 and constant temperature 25˚C. and under different irradiation at constant temperature. The type of PV model used for this study case is Soltech 1STH-215-P PV and its parameter is detailed in Table 3.

The result of the simulation for study case 2 is compared with the previous studies in [13]. Table 4 shows the comparison of PV module with P&O algorithm output at STC and partial condition. It also compares the efficiency of P&O algorithm under STC and partial condition. Meanwhile, Table 5 presents the datasheet of Soltech 1STH-215-P datasheet which is used to validating the simulation results. The results of the simulation are compared with the following datasheet.

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Weather Conditions	Measurement	P&O	Previous Studies
Fixed irradiance G: 1000 W/m2 Constant temperature 25˚C	Io (*A*)	4.5	2.626
	Vo (*V*)	45.1	78.78
	Output power (*W*)	202.9	206.9
	Output *η* (%)	94.3%	97.13%
Partial shading G1: 750 W/m2 G2: 850 W/m2 G3: 800 W/m2 G4: 1000W/m2 Constant temperature 25˚C	Io (*A*)	3.96	2.41
	Vo (*V*)	39.65	69.3
	Output power (*W*)	157.0	159.5
	Efficiency η (%)	72.9%	74.88%

Table 4 Case 2 simulation results

Parameters	Specification
Maximum power (Pmax)	215W
Voltage at Pmax (Vmp)	29.0V
Current at Pmax (Imp)	7.35A
Short Circuit Current (Isc)	7.84A
Open Circuit Voltage (Voc)	36.3V
Temperature coefficient of open circuit voltage (Kv)	-0.361%/˚C
Temperature coefficient of short circuit voltage (Ki)	0.102%/˚C

Table 5 Soltech 1STH-215-P Datasheet

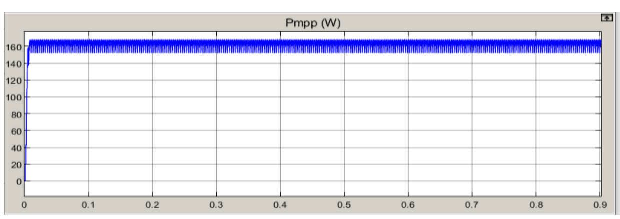

Figure 13 P&O power output under 800 W/m2 irradiance at 25˚C

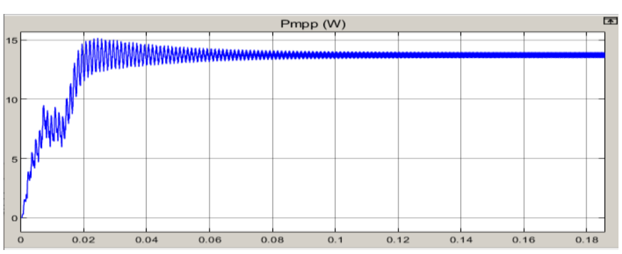

Figure 14 P&O power output under 200 W/m2 irradiance at 25˚C

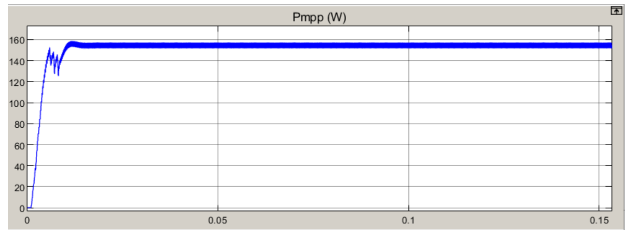

Figure 15 P&O output power under partial shading

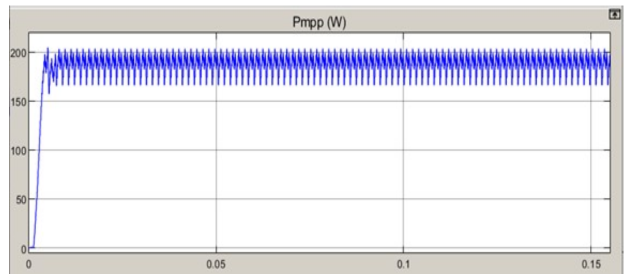

Figure 16 P&O output power under STC

From the results of the simulation obtained, the efficiencyof the P&O algorithm can be discussed. The P&O algorithm can increase the efficiency the of a PV module which can be seen in the results of case study 1, where the efficiency of the PV module when connected to P&O algorithm is 98.03% which nearing 100% under STC. P&O algorithm MPPT technique increases the PV module efficiency by increasing the accuracy of identifying the maximum power point (P_{MPP}).

Case study 2 shows that where the PV module connected to P&O algorithm is simulated under different irradiation and under partial shading condition, as can be seen in Figure 13 and 14, G = 800 W/m^2 and G= 200 W/m^2 respectively. The power output under irradiance 200 W/m^2 tends to oscillate bigger compared to power output under irradiances 800 W/m^2. This shows that tracking accuracy of P&O algorithm depends on irradiances. The tracking accuracy decreases as the irradiance decreases. Figure 15 shows there is a slight delay in reaching the maximum power. This is the effect of partial shading towards the P&O where it increases thetracking time of the P&O algorithm. It takes 15ms for the P&O to identify the P&O algorithm while under constant irradiation as shown in Figure 16, it only takes 6ms to find the maximum power point.

Irradiation (W/m^2)	P&O Power Output (W)
800	168.4
600	121.2
400	56.03
200	15.15

Table 6 PV model with P&O power output under different irradiance at constant temperature 25˚C

5.0 CONCLUSION

In conclusion, through this research, the characteristics of P&O algorithm used in solar MPPT were analyzed. P&O shows great performance under high irradiation where the accuracy of tracking the MPP is high compared to low irradiation. The P&O algorithm tends to oscillate bigger around MPP under low irradiation. Case study 2 also shows the characteristics of P&O algorithm under different weather condition, constant irradiation, and partial shading condition. P&O algorithm have higher tracking speed under constant irradiation compared to partial shading condition. The P&O was also tested under STC and partial shading condition. From the results, it can be observed that the efficiency of P&O algorithm is 94.3% under STC. It also shows the efficiency of the P&O algorithm under partial shading condition where the efficiency dropped to 72.9%.

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