Analysis of MPPT Output Results Based on P&O-Fuzzy and Flow Changes Combination Compared to Classic P&O Algorithms

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ABSTRACT-- Many studies related to energy production efficiency of PV applications have been carried out. The main objective of the development of photovoltaic is to optimize the energy generated by photovoltaic in order to aqcuire optimal electrical power, particularly in environments of very low radiation. This study aims to improve an existing P&O algorithm in order to obtain a more optimal energy output and boost the system in determining the maximum power point in PV. The combination of P&O algorithm and fuzzy algorithm is a decent method in optimizing PV energy. The P&O Algorithm theme was chosen because it characterizes as a simple structure and is easy to comprehend, while the fuzzy algorithm has a very fast response and produces notable output. The development of this algorithm is simulated into matlab simulink. The results of the analysis are taken from the comparison of the output of the classic P&O algorithm with fuzzy P&O algorithm. The results include output voltage (V), flow (I), response time, overshoot voltage, and power efficiency.

Keywords: P&O Algorithm, *Fuzzy* Logic, MPPT, PV, PV *Tracker*.

I. INTRODUCTION

Photovoltaic (PV) is a solar power system that is considered as a technology for alternative power source [1]. PV is the most important renewable energy source because it offers many advantages such as non-fuel based [2].

The application of PV has amplified rapidly as a renewable energy source each year [2]. PV performance depends on light intensity, temperature and weather conditions [3]–[5]. The common problem of PV power is the low energy conversion efficiency and the electrical power produced by PV panels varies in weather conditions [6]. In overcoming low energy efficiency and unstable power, several researchers use the Maximum Power Point Tracker (MPPT) control technique, one of which is in the literature [7]. MPPT control system is used as a maximum power point (MPP) tracking system in all environmental conditions and then forces the PV system to operate at the MPP point [8].

MPPT controls are usually implemented in DC to DC converters, as well as the battery bank required to store excess energy [9]. There are several algorithms used to control MPPT, including fractional short circuit current, incremental conductance (IC), perturb and observe (P&O), artificial-intelligence-based algorithms [10]. One form of PV system research that is often discussed in research is determining the Maximum Power Point Tracker (MPPT) using the Perturb and Observe (P&O) algorithm [11]–[13].

Many preceding researchers stated that the classical P&O method produces large oscillations, has a high overshoot, notable output error value, and has a low efficiency level [2]–[4]. Moreover, the classical P&O method produces a large power ripple with an average efficiency of 97.51% [14].

M.A.A.Mohd Zainuri et.al [15] focused on adaptive interference in the maximum power point tracking (MPPT) method. The inputs used are power change input (ΔP) and voltage change input (ΔV). The combination of fuzzy algorithms is applied to a photovoltaic Kyocera KD210GH-2PU, which is connected to a *dc-dc photovoltaic boost converter*. The results of the research performance include overshoot, response time, oscillation, and stability.

B. Bendib, et, all [16] focused on the effectiveness of using fuzzy algorithm to find MPP generated by photovoltaic and comparing it with conventional P&O algorithm on buck type converter. The application of research testing utilizes SIMULINK matlab to simulate photovoltaic system. The researcher states that the system with conventional MPPT P&O algorithm lost energy. The FL-based MPPT power output increases linearly, while its MPPT P&O technique experiences wide deviations from MPP.

M. Kumar. et, al [5] studied two methods of intelligent control to optimize solar power systems. The researcher suggest that fuzzy logic control is able increase the output of the IC to higher power, with less fluctuations and faster response to changes in weather conduction. Fuzzy control is superior to IC.

II. METHOD

This research covers the stages of developing a classic P&O algorithm from early establishment up until finding the results of the development method. These stages begin by determining the specifications of the solar cell to testing the results of the solar cell simulation using the algorithm developed in the Matlab simulation.

A. Solar Panel Specifications

The solar panel specification pertaining to this study utilizes a solar panel with a specification of 1STH 213WP GH, which will be included in the boost converter circuit. The output of the boost converter is controlled by the MPPT in the form of a duty cycle to adjust the PWM.

B. Photovoltaic Design P&O-Fuzzy Algorithm System

The modeling of this system displays eight blocks, namely PV cells, censors, boost converter circuits, P&O algorithms, fuzzy algorithms, P&O and fuzzy comparison sections and PWM generators, while the load on the PV system is described using a load resistor and calculated mathematically using the boost converter circuit formula. The mapping of photovoltaic system design of the P&O-fuzzy algorithm can be seen in Figure 1.

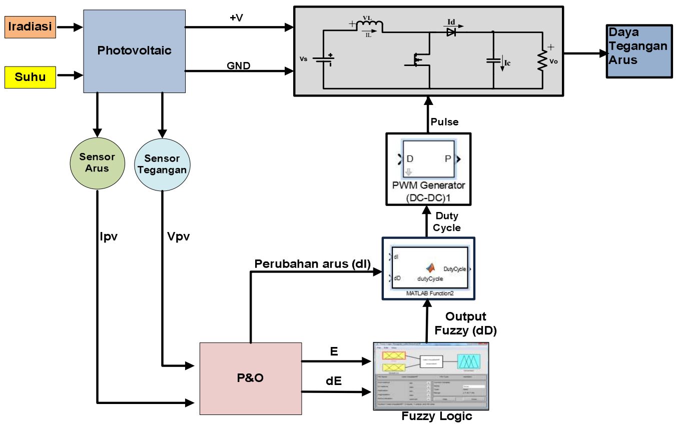

Figure 1. Photovoltaic system modeling

Figure 1. The control block (MPPT control) has two inputs, namely Ipv and Vpv. Ipv and Vpv data are used as source data to calculate P&O algorithms. In accordance with the rules of the P&O algorithm, this algorithm functions to find the value of the comparison of P and V, which will be used as an *increment duty*. In addition, the alteration in flow (dI) is used as an indicator that there has been a change in irradiation. It is to note that if there is a fluctuation in the increase in P while the value of V stays, there will be an increase in the variation of dI due to an irradiation growth.

Based on the specifications of the solar panels that will be used in the study, the maximum flow (Impp) of the solar panels in the description is 7.34 A. Therefore, when there is an increase in irradiation of (H) at a maximum state of 1000W/m2, the current flowing is 7.34 A. This research method employs a grouping system of two variations in irradiation (ΔH), namely large irradiation fluctuations if H value >= 100 W/m2 and small irradiation fluctuations if H value < 100 W/m2. Each times the irradiation increases or decreases by 100 W/m2, the flow differs as well whether it increases or decreases. For every 100W/m2 of irradiation fluctuations will affect the flow of about 1/10 ampere of the maximum flow of 7.34 A.

The calculation of these fluctuations is based on the STC irradiation reference of 1000W/m2 which is capable of issuing a maximum flow of 7.34 A. Thus, it is postulated that each time there is a change in the increase of irradiation by 100W/m2, the flow will change for about 0.734 A. The dI equation used to determine the magnitude of the variation in irradiation is shown in equation (1).

$$\Delta H / 1000 = dI / Impp \qquad (1)$$

The PV simulation test with 100W/m2 irradiation resulted in an output flow of 0.73 A at the mpp point. In the 200W/m2 irradiation test, the output flow is 1.47 A at the mpp point and when the irradiation is increased by 300W/m2, the flow obtained is 2.21 A at the mpp point. From the results of those PV simulation tests, there is a 0.001A flow change. The alterations in flow are used as an *incremental duty cycle* at the fuzzy output value. Because the change in flow is directly proportional to the change in irradiation, equation (2) is obtained:

$$Increment = dI / Impp \times 0{,}001 \qquad (2)$$

Meanwhile, the fuzzy algorithm is used as an error response or error change (delta error) if an error occurs which is measured by the P&O algorithm.

C. Fuzzy Method Application System

The merging of the fuzzy method and the P&O method is carried to speed up the system in determining the MPP. The fuzzy method aims to determine the error (E) that occurs in alterations of power and voltage and produces an output in the form of a crips value that regulates the increment duty cycle (ΔD).

An error with a positive (+) value indicates that the work area remains to the left side of the MPP. Similarly, if the ratio of the variation in power (ΔP) with the variation in voltage (ΔV) is smaller than the previous value, the change in the error value is negative. Figure 2 shows a graphic example of an analogy for determining the error value in the fuzzy method.

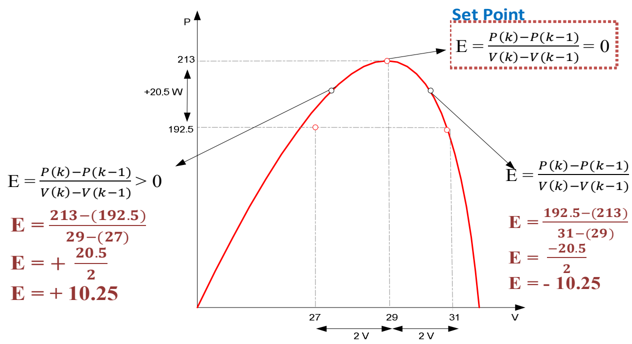

Figure 2. A graphic diagram of determining the error value.

In Figure 2 when the error is greater than 0 (E > 0) then the duty cycle value will be reduced by adjusting the Vref. Correspondingly, if the error is less than 0 (E < 0) then the duty cycle value will be increased through Vref adjustment. The output of E and ΔE value is (ΔD) which is used to set the increment value when there is an error in determining the MPPT in the P&O algorithm.

The membership function of each input E and ΔE is equally divided into seven parts. The more membership functions, the lower possibility of errors in measurement will occur. The membership function used consists of Large Negative Error (ENB), Medium Negative Error (ENS), Small Negative Error (ENK), No Error (TE), Small Positive Error (EPK), Medium Positive Error (EPS), and Large Positive Error (EPB).

The consequent length of the membership function based on the assumption of range is derived from the maximum error value obtained from the comparison of the maximum power change with the maximum voltage change ΔP max /ΔVmax.

$$\text{Range value E} = \frac{\text{Pmax}-\text{Pmin}(k-1)}{\text{Vmax}-\text{Vmin}(k-1)} \quad (3)$$

$$\text{Range value} \quad E = \frac{213-0}{29-0} = 7.35$$

The result of consequent membership function error can be seen in Figure 3.

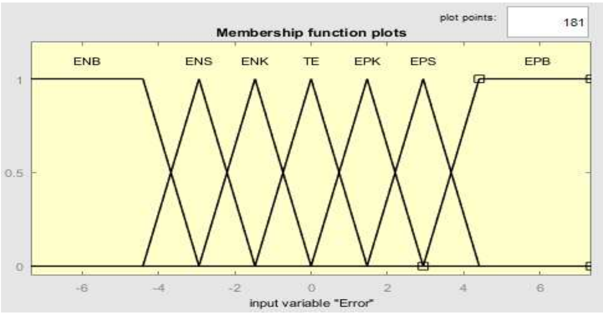

Figure 3. Result of membership function error.

As for the range of membersip function delta error is set to be smaller than the error range. The postulation of setting the delta error range is set smaller because the value of the delta error is obtained from the result of reducing the current error E (k) minus the previous error value E (k-1). The results of determining the degree of membership of the delta error can be seen in Figure 4.

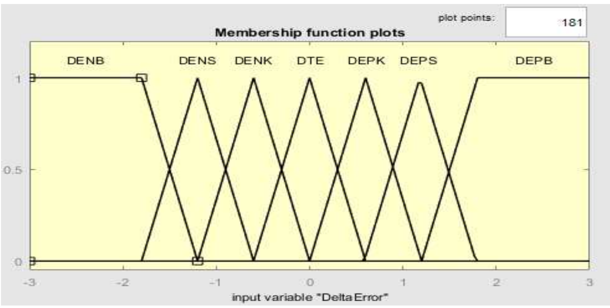

Figure 4. Result of membership function delta error.

D. Rule Base

Rule Base is used as a relation rule or the implications of fuzzy logic path in the form of "IF-Then". In the fuzzy logic design that is used based on the reference degree of membership, it has 49 rule bases. The formula of the rule base can be seen in table 1.

Table 1. *Rule Base*

E / ΔE	ENB	ENS	ENK	TE	EPK	EPS	EPB
DENB	PBI	PBI	PBI	PMI	PMI	PSI	PSI
DENS	PBI	PMI	PMI	PMI	PSI	PSI	ZI
DENK	PBI	PMI	PMI	PSI	PSI	ZI	NBI
DTE	PBI	PMI	PSI	PSI	ZI	NMI	NBI
DEPK	PMI	PSI	PSI	ZI	NMI	NMI	NBI
DEPS	PSI	PSI	ZI	NMI	NMI	NMI	NBI
DEPB	PSI	ZI	NMI	NMI	NBI	NBI	NBI

Based on table 1, it shows that the rule base being used is not linear. Surface results constructed on the rule base used can be seen in Figure 5.

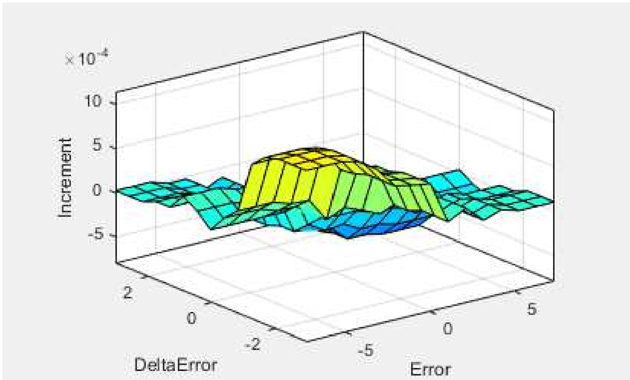

Figure 5. Surface form of rule base

The rule base trial that is applied is based on experimental tests on the fuzzy algorithm. The experimental trials were conducted to determine the appropriate rule base on the fuzzy system in determining the duty increment.

E. Defuzzification

The result of defuzzification is using fuzzy mamdani. By using fuzzy mamdani, the defuzzification process is carried out in centroid mode or by calculating the moment and area. This method system is carried out by taking all the fuzzy regions from the results of the composition of the rules used in combination with the aim of forming appropriate results and taking the center point of the fuzzy area. The associated mathematical formula for the centroid method on fuzzy mamdani can be seen in equation (4).

$$Z = \frac{\int \mu s(X) \,.\, X \, dx}{\int \mu s\,(A)\, dA} \quad (4)$$

Note :
X : moment
A : Area

F. MPPT Solar Panel Schematic

The test scheme can be seen in Figure 6. The test scheme is created and simulated in Matlab Simulink. The system was tested using several variables of light intensity (irradiant).

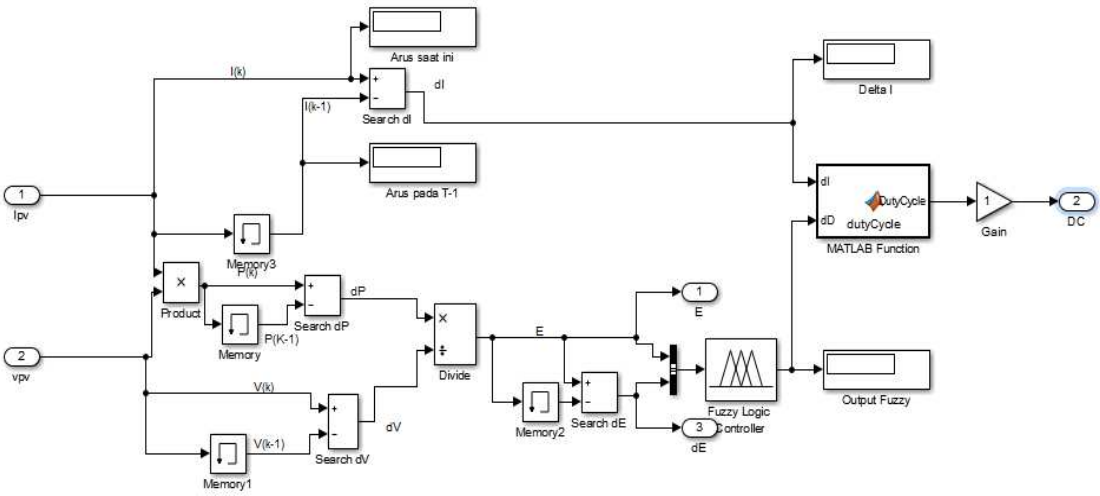

Figure 6. P&O-fuzzy Control System

Figure 6 shows a working MPPT control system using the P&O-fuzzy algorithm. Power is obtained from the current sensor and voltage sensor.Power is obtained from current sensors and voltage sensors. If the change in power along with the change in voltage is smaller than before ($\Delta P/\Delta V<0$), an incremental duty cycle (ΔD) will be controlled.The value of the increment duty cycle is obtained from the fuzzy input error and error changes.The increment duty cycle will be collaborated with the change in current (ΔI) in regulating the PWM in controlling the mosfet.If the change in power and the change in voltage is greater than before,the increment duty cycle reduction control will be carried out. The duty cycle change refers to the four input changes. The greater the increase in the change in power and input voltage, the greater the PWM that will be issued by the controller to adjust the duty cycle and the smaller the change in the decrease that occurs at the input, the smaller the PWM that will be issued to regulate the duty cycle. The reference has a stipulation that, if the current change in power and voltage is the same as the previous change in power and voltage, the current duty cycle must be the same as the previous duty cycle. However, if there is an unsynchronized change in the current power or voltage with the previous power or voltage, it is necessary to increase or decrease the duty cycle.

III. RESULT AND DISCUSSION

The concluding quantitative research results are based on simulations in Matlab Simulink. The quantitative value is the result of the comparison of the use between P&O-fuzzy algorithm and the classical P&O algorithm based on variations in sunlight irradiation. This study resulted in five structured measurements starting from power efficiency, comparison of output power, response time, absolute error and percentage error of power, output voltage, and the resulting flow.

A. Output Power Efficiency

Based on the test curve for variations in solar irradiation, the output power efficiency of the boost converter circuit is almost close to the ideal photovoltaic with variable irradiation input. Power efficiency indicates that very little power is wasted.

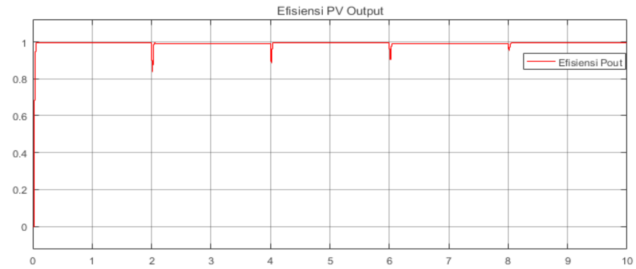

Figure 7. P&O-*fuzzy* Output Power Efficiency Curve

The power efficiency generated by the P&O-fuzzy algorithm in Figure 7 shows an average of 99.5%, which is close to the ideal power. The results are displayed on a measurement scale of 1: 100. Hence, the P&O-fuzzy efficiency is almost close to one, which means 100%.

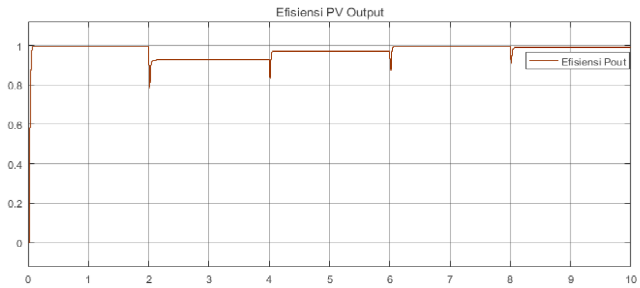

Figure 8. P&O Algorithm MPPT Power Output Efficiency

The classic P&O in figure 8 shows when the irradiation is increased to maximum, the power efficiency obtained is only 98%. Moreover, there is an objectively large power difference in the algorithm when the irradiation is 400 W/m2. The power generated in the test system has an output efficiency of about 92.90% of the reference PV power (ideal PV). When the irradiation is increased to its maximum, the resulting power efficiency is only close to 98%.

B. Power Output Comparison

The power comparison system is carried out by observing the output of the MATLAB simulation. The data taken is based on the output of each power generated when there is a variation in irradiation.

Table 2. Power Output

Irradiation	Power Reference	Pout P&O	Pout P&O-Fuzzy
250	53.3	53.1	53.22
300	63.9	52.1	64.2
400	85.2	79.6	85.89
500	106.5	103.3	107
600	128	124.8	128
700	149.1	148	150.2
800	170	169.9	170
900	191.7	190	191
1000	213	211.2	212.89

On table 2, it shows that the power generated by the P&O-fuzzy algorithm is on average superior compared to the P&O algorithm. At maximum irradiation, the P&O-fuzzy algorithm is able to produce power close to the ideal which is used as a reference.

C. MPPT Time Response

Response time is taken based on observations of the form of the output response to changes in time. There are two response time specifications, which are transient response specifications and steady state specifications, but what is taken in this study is the transient response because the observations start from the occurrence of changes in the input signal until the response enters a steady state.

The result of the rise time value is taken based on the time taken by power change coming out of the boost converter circuit at a reference point of 0 to 100%.

Table 3. *Rise Time* Based On Irradiation Changes

Irradiation	Rise Time Classic P&O	Rise Time P&O-Fuzzy
250	32.495	32.495
300	17.91	25.383
400	25.146	18.91
500	19.521	19.383
600	18.251	18.547
700	19.618	18.713
800	18.737	17.243
900	17.439	17.544
1000	18.084	17.183

Based on the data in table 3, the rise time in several irradiations on the classic P&O system is indeed superior but does not reach the specified peak value (Peak Time). As a result, the classic P&O algorithm does not meet the ideal PV power. While the settling time of the two algorithms remains normal because the wave oscillations can last around 2% according to the time required.

The overshoot and undershoot results are taken when the signal exceeds or is below the average value that has been determined. Based on the results of the study, the average overshoot and undershoot were obtained for each irradiation. The average overshoot of classic P&O is 2.59% while P&O-fuzzy is 1.05%. Meanwhile for classic P&O undershoot is 3.98% and P&O-fuzzy is 2.67%

D. Power Error Value

Table 4 shows the MPPT P&O-fuzzy algorithm can operate well, has a significantly low absolute error value compared to the classical P&O. Therefore, the application of the P&O-fuzzy algorithm is able to overcome the energy output waste.

Table 4. Absolute Power Error of The Two Algorithms

Irradiation	Absolute Error		Percentage Error	
	P&O Classic	P&O-Fuzzy	P&O Classic	P&O-Fuzzy
250	0.09	0.067	0.17%	0.13%
300	11.850	0.26	18.70%	0.41%
400	5.688	0.57	6.67%	0.67%
500	3.380	0.99	3.18%	0.92%
600	2.840	0.88	2.20%	0.69%
700	1.020	0.85	0.68%	0.57%
800	0.286	0.084	0.17%	0.05%
900	0.760	1.45	0.39%	0.75%
1000	1.360	0.88	0.63%	0.41%

E. Voltage Output

Comparison of voltage output measurements of both algorithms using the lowest irradiation of 250 W/m2 to the maximum irradiation of 1000 W/m2, the following figure 9 illustrates the voltage ratio curve.

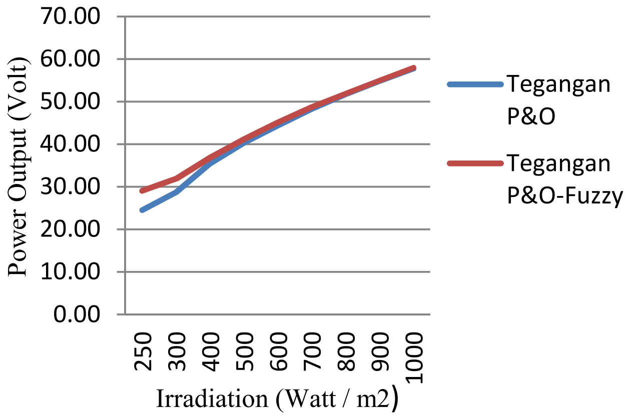

Figure 9. Voltage Comparison Curve.

As shown in figure 9, the P&O-fuzzy algorithm is able to produce a voltage of 57.95 volts with a maximum irradiation of 1000 W/m2. The voltage is almost close to the calculated reference voltage of 58 volts. While the results of the classic P&O algorithm test are only able to produce an output voltage of 57.70 volts.

F. Flow Output

This curve test comparison is conducted based on the flow output results generated by the two algorithms. The flow output the P&O-fuzzy algorithm is superior compared to the classic P&O algorithm. The following figure 10 curve illustrates the ratio of the output flow.

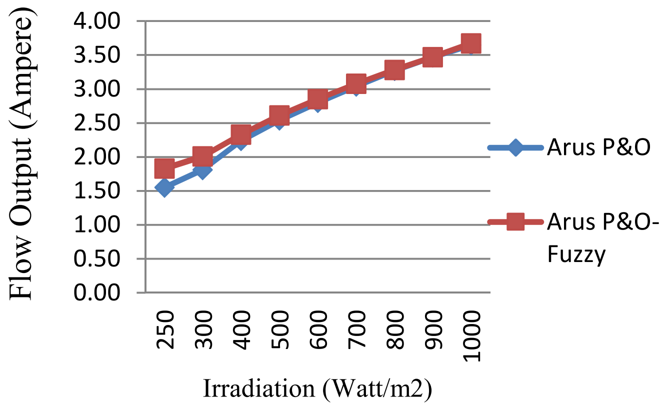

Figure 10. Flow Comparison Curve P&O-*fuzzy* and P&O Classic.

In Figure 10, it can be seen that the output flow based on the fuzzy P&O algorithm is superior to the classical P&O. Especially in the initial irradiation test with irradiation of 250 W/m2 and 300 W/m2. The P&O-fuzzy algorithm was able to produce currents of 1.83 amperes and 2.01 amperes, in contrast to the classical P&O algorithm which was only able to issue 1.55 amperes and 1.81 amperes. Even though when the irradiation increases the difference between the two algorithms is reduced, but at maximum radiation the output of the fuzzy P&O algorithm is still superior to the classical P&O algorithm. In the P&O-fuzzy current, the average flow generated for each radiation change is 2.79 amperes, while the classical P&O algorithm is able to produce an average flow of 2.71 amperes.

IV. CONCLUSION

Based on the research that have been carried out, it can be concluded that based on simulation trials using the P&O-fuzzy algorithm is able to produce a power output that is almost in accordance with the reference power output or ideal value. MPPT with P&O-fuzzy algorithm is able to produce much better output compared to the classic P&O, in terms of voltage, flow, output power, and response time. MPPT with P&O-fuzzy algorithm has higher efficiency than classical P&O. At the time of maximum irradiation, the P&O-fuzzy Algorithm has a difference in response speed (response time) of 2.36 ms faster than classical P&O. The results of the MPPT power output with the P&O-fuzzy algorithm also produce a smaller error than the classical P&O.

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