Fuzzy based MPPT Control System in Grid Connected Solar Plant

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***Abstract*—The increase in demand for the electricity system is increasing. Thus, enviromentally friendly technologies such as new and renewable energy are needed, one of which is a power plant with Photovoltaic as the main component. Solar power plant has enviromentally friendly properties. The design of this solar power plant uses Fuzzy Logic Controller and PI Controller methods, where both methods are used to find the maximum power peak point used for fast charges and MPPT, which is simulted using MATLAB/Simulink. The things presented in developing the generating system using these two methods are solar radiation intensity, temperature and Photovoltaic module. The model developed will make it possible to examine the characteristics of solar power plant and predict the amount of energy generated by solar panels in a particular location and compare the effectiveness of Fuzzy Logic and PI methods. The results shows that Fuzzy method produces a boost converter output voltage in the range of 600 V with result that are still not good and less stable, but the irradiation of 100 W/m^2 voltage is stable, while the boost converter output voltage controller by the PI method is very good and stable in all conditions. Radiation and voltage are also in the range of 600 V.**

***Keywords*—Renewable energy, photovoltaic, fuzzy logic, PI, MPPT, matlab software.**

I. Introduction

Global warming and climate change is one of the main issues all over the world. Countries such as USA, Canada, UK, and China have agreed to reduce the effect of global warming by using renewable based power plant as the main sources [1]. Developed countries are also following their step by making a massive target for increasing penetration of renewable based power plant [2]. Indonesia is also following the developed country to enhance the application of renewable based power plant [3]. Among numerous types of renewable based power plant solar photovoltaic (PV) power plant is becoming favorable in Indonesia.

Solar PV power plant could provide clean and sustainable energy to the grid. Hence this type of power plant could help the environment to reduce the effect of global warming. Another reason why choosing PV plant as of the renewable based power plant in Indonesia is the abundant solar energy in Indonesia. In all region of Indonesia the solar radiation intensity average is 4.8 kW/m², this is because Indonesia is located on the equator [4].

The application of PV as power plant is reported in [5]. In [5], PV plant is used as isolated power generation. Research effort in [6] is also how efficient PV technology as the renewable based power plant. However, in reality, the amount of radiation from the sun that solar panels can receive always changes over time due to conditions [7]. In addition, an increase in the environmental temperature of the solar panel can affect the decrease in the output voltage, which causes the output power not to be generated efficiently [8]. Weather conditions are one of the main problems in installing solar panels. Hence, to get the maximum power extraction from the sun maximum power point tracking (MPPT) algorithm is essential.

Generally, the method for tracking the maximum power from the sun is using perturb and observe (P&O) method. The P&O algorithm can track the maximum power point of the solar panel when the irradiation state and temperature fluctuate. The application of P&O algorithm for PV energy harvesting chip is reported in [9]. From the results it is found that P&O method could track a better energy of the PV. The application of P&O algorithm for MPPT on the partial shading condition is reported in [10]. Perturb and observe method application is also reported in [11]. However, this algorithm has the disadvantage that it has a large output power ripple when operating under normal conditions [12]. Hence, intelligent method such as fuzzy logic controller (FLC) can be solution to handle this problem.

FLC can handle complex systems such as MPPT by knowing the solar panels' power and voltage errors (dP/dV). Based on the error (dP/dV) the step size or duty cycle change ("ΔD") on the DC-DC converter will be determined periodically until the maximum power point is reached. Research effort in [13], shows the efficacy of FLC for MPPT for PV system. In [13], the boost converter is used as the device for MPPT algorithm. Moreover, FLC is used as the controller of boost

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converter to provide a better duty cycle. From the results it is noticeable that FLC can provide high efficiency for harvesting energy from PV.

This paper focused on the application of FLC as MPPT on grid solar PV power plant. The rest of the paper is organized as follows: Section II shows the theoretical basis of the research. Method for designing the method is illustrated in the Section III. Section IV provide the experimental results and discussions. Section V highlight the conclusions of the study.

II. Theoretical Basis

A. Fuzzy Logic

FLC has become very popular in recent years because it works with imprecise inputs, does not need accurate mathematical models, is simple in design, and can also handle system non-linearity. This includes three steps, namely fuzzification, inference, and defuzzification [14]. Fuzzy logic is an advanced variant of soft computational multi-value logic. It can handle variable truth values, which may be a real number between 0 and 1. Boolean logic has a completely different approach. The true value of a variable can only hold an integer value of 0 or 1. Fuzzy logic proves that it is feasible with a formidable utility for dealing with the concept of partial truth, where the truth value can range between completely true and completely false. These advantages of Fuzzy Logic Controllers can be exploited for the successful implementation of maximum power point tracers in photovoltaics [15].

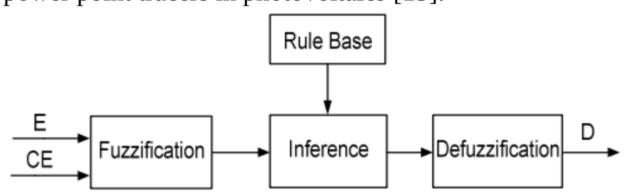


Figure 1. Fuzzy controller block diagram

The two inputs, namely change of error (CE) and error (E), are defined as [16],

$$E(k) = \frac{P_{PV}(k) - P_{PV}(k-1)}{V_{PV}(k) - V_{PV}(k-1)} \quad (8)$$

$$CE(k) = E(k) - E(k-1) \quad (9)$$

Ppv is the instantaneous power of the PV array fuzzy inference processed using the Mamdani method, and Defuzzification uses the center of gravity to process the output, which is a duty cycle [16].

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \quad (10)$$

The fuzzy rule bases used in this study are given in Table 1 and Table 2 as [17], input and output variables, based on their ranges, are assigned to different fuzzy sets denoted by linguistic variables. Each linguistic variable is defined with a specific membership function. This function converts crisp values into fuzzy values. A set of membership functions is defined for five fuzzy variables, each NB (Negative-Big), NM (Negative-Medium), NS (Negative-Small), ZE (Zero-Equal), PS (Positive-Small), PM (Positive-Medium), and PB (Positive-Big) [18].

Table 1. MPPT fuzzy logic rule

CE / E	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	NM	NM	NS	NS
NS	PB	PM	PS	NS	NS	NM	NS
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NB	NM	NS	PS	PS	PM	PB
PB	NB	NB	NM	PM	PM	PB	PB

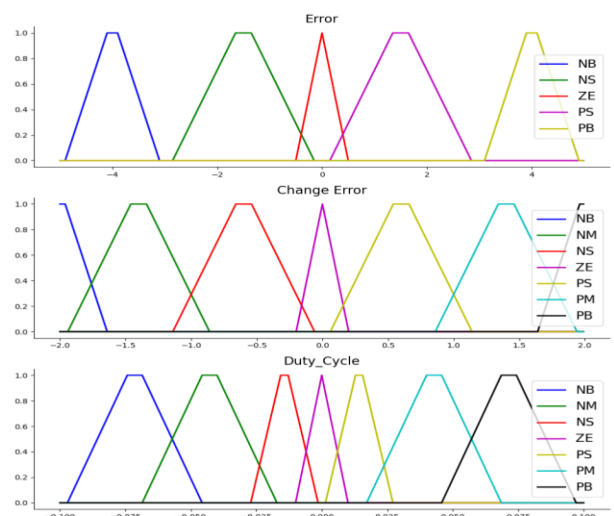


Figure 2. Plotting of MPPT fuzzy logic rule

Table 2. Fuzzy logic battery rule

ΔE / E	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS

ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

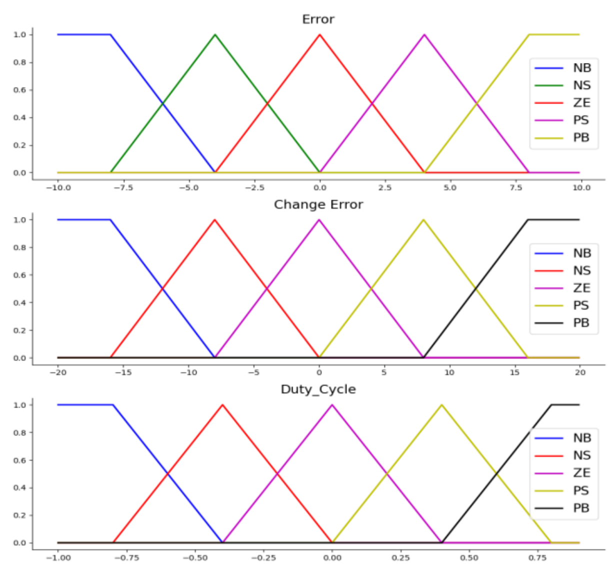


Figure 3. Plotting of battery fuzzy logic rule

B. Three Phase Inverter

Inverters are used in many applications whose main function is to convert direct voltage into alternating voltage. For inverter selection, various topologies are available according to your needs, such as Voltage Source Inverter (VSI) and Current Source Inverter (CSI), either single-phase, three-phase, or multilevel. VSI provides better performance and is also more efficient than CSI [19]. Inverters use pulse width adjustment using a switch, which is useful for deciphering the AC output voltage such as a sine wave [19]. In a solar power generation system, the inverter is the main component for converting direct voltage into alternating voltage according to load requirements [20].

LC filters are used to suppress the harmonics generated by the switching operation of the power electronic converters. Here, the filter design plays an important role in connecting to the local grid as the current harmonics must be kept within safe limits defined by the standard. The filter parameters are designed based on the combined objective by minimizing the cost function, total harmonic distortion (THD), and time delay. The transfer function concept is used to design the LC filter parameters [21]. The three-phase inverter power circuit with an output LC filter considered in this journal is shown in Fig. 4. The converter and filter model is presented here, and the load is assumed to be unknown. The switching state of the converter is determined by the gating signals Sa, Sb, and Sc as follows [22]:

$$S_a = \begin{cases} 1: if\ S_1\ is\ on\ and\ S_4\ is\ off \\ 0;\ if\ S_1\ is\ off\ and\ S_4\ is\ on \end{cases} \quad (11)$$

$$S_b = \begin{cases} 1: if\ S_2\ is\ on\ and\ S_5\ is\ off \\ 0;\ if\ S_2\ is\ off\ and\ S_5\ is\ on \end{cases} \quad (12)$$

$$S_c = \begin{cases} 1: if\ S_3\ is\ on\ and\ S_6\ is\ off \\ 0;\ if\ S_3\ is\ off\ and\ S_6\ is\ on \end{cases} \quad (13)$$

and can be expressed in vectorial form with [13],

$$S = \frac{2}{3}(S_a + aS_b + a^2S_c) \quad (14)$$

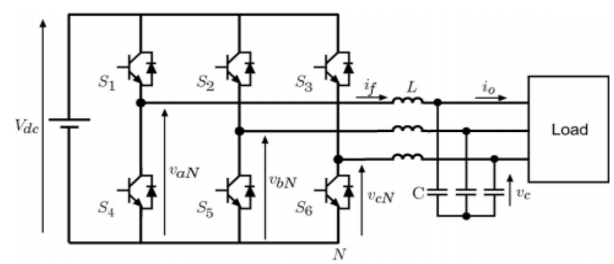


Figure 4. Three phase inverter with LC filter output

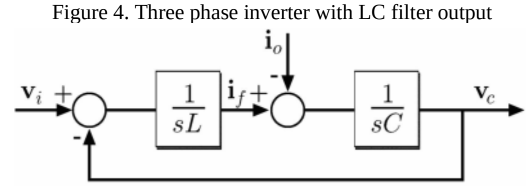


Figure 5. Model LC filter

C. Boost Converter

Boost converters are used in renewable energy systems to increase the constant DC output voltage to the higher voltages required by the load and battery. The design and development of boost converters mainly concern efficiency, output power, and ease of design. Renewable energies such as solar and wind use a boost converter as a power transmission medium for energy absorption and injection into loads and batteries, as shown in Fig. 6 [24].

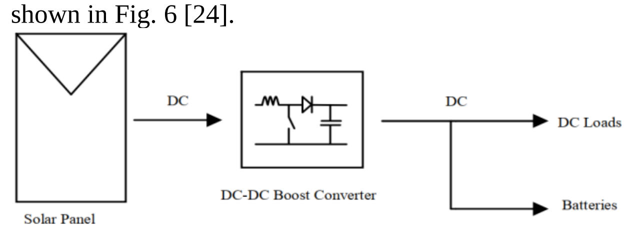


Figure 6. Block diagram of the solar system

The energy absorption and injection process are carried out by a combination of four components, namely inductor, electronic switch, diode, and output capacitor. The boost converter circuit is shown in Fig. 7. The process of absorption and injection of energy is a switching cycle. In other words, the average output voltage is controlled by the duration of turning it on and off. At a constant switching frequency, adjusting the duration of on and off the switch is called pulse width modulation switching. The task switching cycle, k is defined as the ratio of the duration to the period of time switching. The absorption and injection of energy with the relative duration of the switching period will operate the converter in two different modes known as continuous conduction mode and stopped conduction mode [24]. For the boost converter specifications in this design, it can be seen in Table 3.

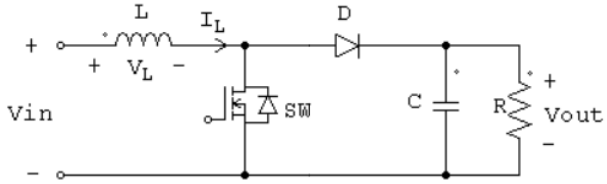


Figure 7. Boost converter

Table 3. Boost converter specifications

Parameter	Value
Input voltage	492.8 V
Output voltage	600.2 V
Switching frequency	10 kHz
Inductor	1.45e-3 H
Capacitor	3227e-6 F
Resistor	1e-3 Ω
Capacitor 1	1000e-6 F

III. Method

The methodology used in the MPPT control system based on fuzzy logic in solar power plant includes literature review, design and modeling, data analysis. Fig. 8 shows the simulation flow carried out on the MPPT Control System Based on Fuzzy Logic at a Solar Power Plant, starting from modeling to getting results in the form of data from the analysis.

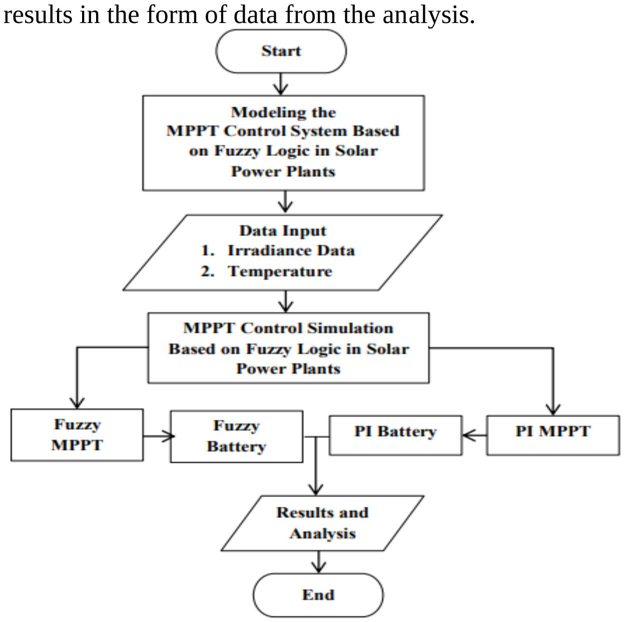


Figure 8. Flow chart of MPPT simulation

Modeling is done using Matlab Simulink, as well as the developed simulation model allows for creating solar cell characteristics in real form, predicts the amount of energy produced under certain conditions, identify the optimal operating conditions of the Photovoltaic installation.

The simulation conditions are as follows: determination of radiation and temperature, the simulation uses 1Soltech 1STH-215-P solar cell module data.

IV. Results and Discussion

A. Fuzzy MPPT Analysis

The first case study is to discuss the MPPT system with fuzzy methods and capricious radiation giving. Fig. 9 shows the test system of this case study. The experiment aims to see the performance reaction of the MPPT which is applied in the control system.

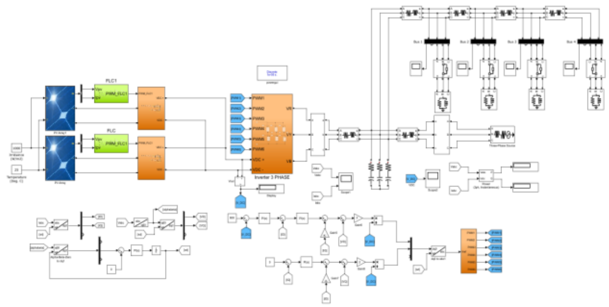


Figure 9. Simulink MPPT control system based on fuzzy logic in a solar power plant using Matlab R2017a

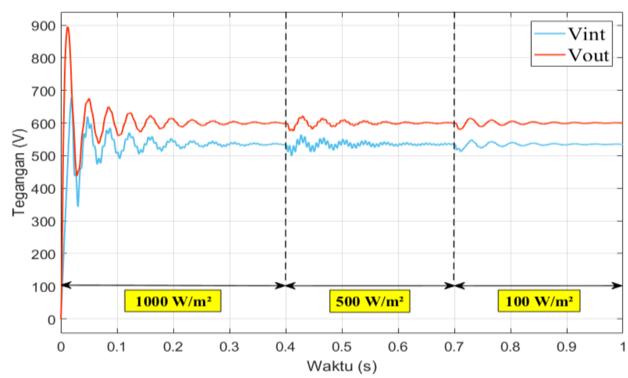


Figure 13. Boost converter voltage graph

Fig. 10 shows the results of the boost converter working voltage, when given radiation varies start from 1000 W/m² at seconds 0 to 0.4, 500 W/m² at seconds 0.4 to 0.7, and 100 W/m² at seconds 0.7 to 1 with giving the same temperature for each change in radiation, that is 25°C. Fig. 13 shows that the boost converter output voltage controlled with MPPT based on Fuzzy Logic is quite good and quite stable with an output voltage of 598.6 V at 1000 W/m² radiation, 600.2 V at 500 W/m² radiation and 599.9 V at radiation 100 W/m².

B. MPPT PI Analysis

The second case study is to discuss the MPPT system with the PI method and varying radiation giving covering 1000 W/m², 500 W/m², 100 W/m² as shown in Fig. 11. The experiment aims to see the performance reaction of the MPPT which is applied in the control system.

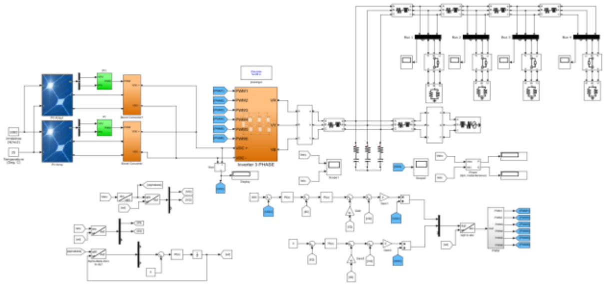


Figure 11. Simulink MPPT control system based on PI in a solar power plant using Matlab R2017a

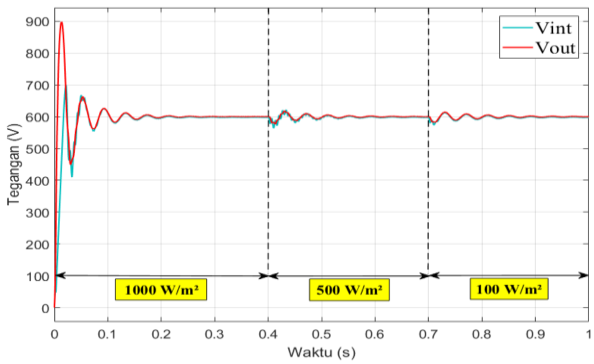


Figure 12. Boost converter voltage graph

Fig. 12 shows the results of the boost converter working voltage, when given radiation varies start from 1000 W/m² at seconds 0 to 0.4, 500 W/m² at seconds 0.4 to 0.7, and 100 W/m² at seconds 0.7 to 1 with giving the same temperature in each radiation change that is 25°C. Fig. 12 shows that the boost converter output voltage controlled with PI-based MPPT is better and stable when compared to MPPT based on Fuzzy Logic with an output voltage of 599.9 V at 1000 W/m² radiation, 599.8 V at 500 W/m² radiation and 599.9 V at 100 W/m² radiation. For more details, it will be explained separately, following the two methods, the graphs are put together and the results can be seen as shown in the figure below.

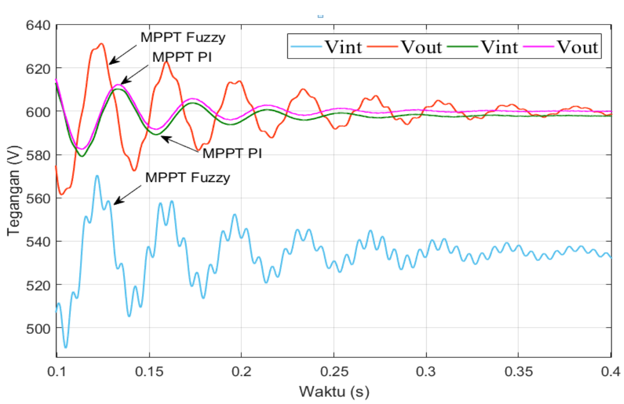


Figure 13. Boost converter voltage graph using MPPT Fuzzy and MPPT PI radiation 1000 W/m²

Fig. 13 shows the results of the boost converter working voltage, both input and output, which when given 1000 W/m² radiation. It can be studied more deeply that the input and output voltages of the boost converter using MPPT PI are good and in a steady-state condition at seconds 0.4 with an input voltage of 597.8 V and an output voltage of 599.9 V at seconds 0.4. Meanwhile, for MPPT Fuzzy, there are still no signs of a steady-state in seconds 0.4 with a boost converter voltage on the input side of 532.5 V and the output side of 598.6 V. When compared to the boost converter voltage at seconds 0.4 between those using MPPT PI and MPPT Fuzzy on the input voltage side, so the voltage difference is very far, that is 65.3 V. Whereas for the difference in the output boost converter voltage between MPPT PI and MPPT Fuzzy is not too far away, that is 1.3 V.

Table 4. Voltage boost converter using MPPT Fuzzy and MPPT PI radiation of 1000 W/m² at 0.4s

MPPT PI		MPPT Fuzzy		Difference in Voltage	
Voltage		Voltage		Voltage	
input	output	input	output	input	output
597.8	599.9	532.5	598.6	65.3	1.3

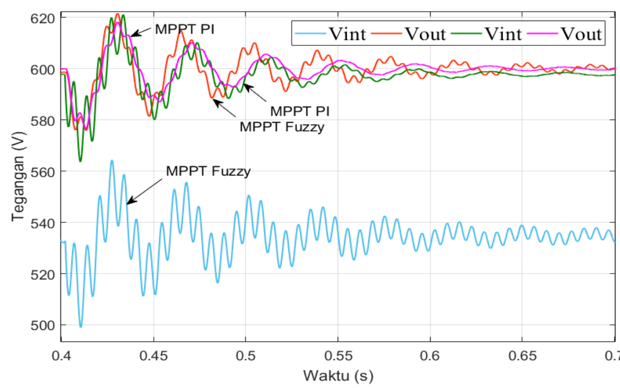


Figure 14. Boost Converter voltage graph using MPPT Fuzzy and MPPT PI radiation of 500 W/m²

Fig. 14 shows the results of the boost converter working voltage, both input, and output, which when given 500 W/m² of radiation. It can be studied more deeply that the input and output voltages of the boost converter using MPPT PI are good and in a steady-state condition at seconds 0.7 with an input voltage of 597.6 V and an output voltage of 599.8 V at seconds 0.7. Meanwhile, for MPPT Fuzzy there are still no signs of a steady-state at seconds 0.7 with a boost converter voltage on the input side of 532.4 V and the output side of 600.2 V. When compared to the boost converter voltage at seconds 0.7 between those using MPPT PI and MPPT Fuzzy on the input voltage side, so the voltage difference is very far that, is 65.2 V. Whereas for the difference in the output boost converter voltage between MPPT PI and MPPT Fuzzy is not too far away, that is 0.4 V.

Table 5. Voltage boost converter using MPPT Fuzzy and MPPT PI radiation of 500 W/m² at 0.7s

MPPT PI		MPPT Fuzzy		Difference in Voltage	
Voltage		Voltage		Voltage	
input	output	input	output	input	output
597.6	599.8	532.4	600.2	65.2	0.4

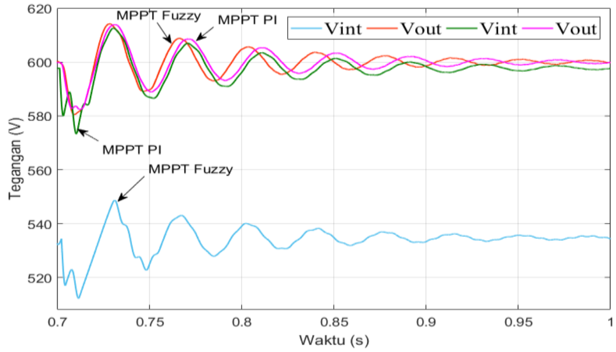


Figure 15. Boost converter voltage graph using MPPT Fuzzy and MPPT PI radiation 100 W/m²

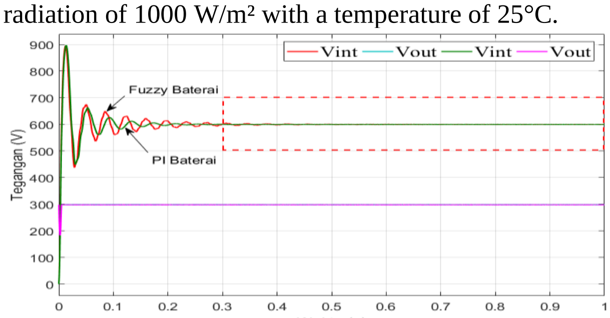
Fig. 15 shows the results of the boost converter working voltage, both input and output, which when given 100 W/m² radiation. It can be studied more deeply that the input and output voltages of the boost converter using MPPT PI are good and in a steady-state condition at seconds 1 with an input voltage of 597.6 V and an output voltage of 599.9 V at seconds 1. Meanwhile, for MPPT Fuzzy, signs are already visible in the steady-state at seconds 1 with a boost converter voltage on the input side of 534.4 V and the output side of 599.8 V. When compared to the boost converter voltage at seconds 1 between those using MPPT PI and MPPT Fuzzy on the input voltage side, so the voltage difference is very far, that is 63.2 V. Whereas for the difference in the output boost converter voltage between MPPT PI and MPPT Fuzzy is not too far away, that is 0.1 V.

Table 6. Voltage boost converter using MPPT Fuzzy and MPPT PI radiation of 100 W/m² at 1s

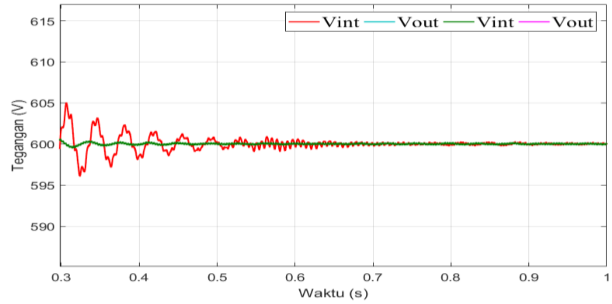
MPPT PI		MPPT Fuzzy		Difference in Voltage	
Voltage		Voltage		Voltage	
input	output	input	output	input	output
597.6	599.9	534.4	599.8	63.2	0.1

C. Batttery Fuzzy and PI Analysis

The third case study is to discuss the fuzzy battery system and battery PI, which aims to see the effectiveness of the method, which is used to control the Bidirectional Buck-Boost Converter in order to produce a stable voltage output under maximum voltage conditions. For this experiment, using radiation of 1000 W/m² with a temperature of 25°C.



(a)



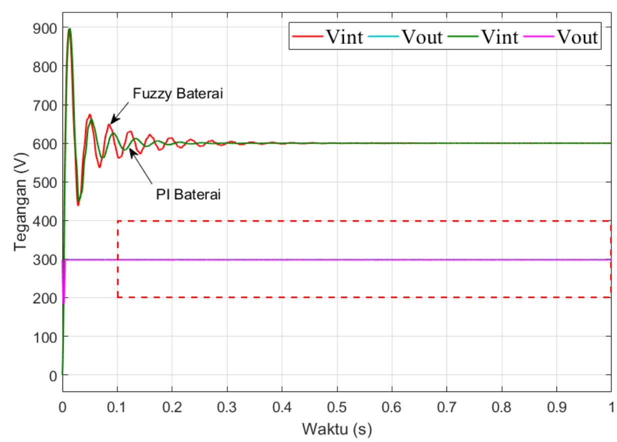
(b)

Figure 16. Buck-boost converter bidirectional voltage graph using Fuzzy and PI Method with radiation of,
(a) 1000 W/m², (b) 1000 W/m² at 0.3s-1s

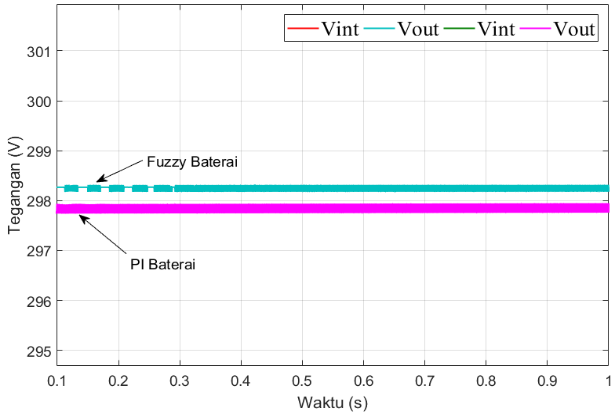
Fig. 16 (b) shows the results of the input working voltage of the bidirectional buck-boost converter, which is when 1000 W/m² of radiation is applied. It can be studied more deeply that the bidirectional buck-boost converter input voltage using PI is already good and in steady-state conditions in 0.5s-1s seconds with an input voltage of 599.97 V. Whereas for Fuzzy, there are signs that in steady-state conditions are 0.7s-1s with a boost converter input voltage of 600.03 V. When compared to the bidirectional buck-boost converter input voltage using the PI and Fuzzy methods for the process to steady-state faster the PI system than the Fuzzy system with a time difference of 0.2s which can be seen from the graph above.

Table 7. Input voltage bidirectional buck-boost converter using Fuzzy Battery and PI Battery radiation of
1000 W/m² at 1s

PI Battery	Fuzzy Battery	Time Difference for Steady State
V input	V input	Fuzzy(s) – PI(s)
599.97	600.03	0.2



(a)



(b)

Figure 20. Graph of bidirectional buck-boost converter output voltage using Fuzzy and PI with radiation of, (a) 1000 W/m², (b) 1000 W/m² at 0.1s-1s

Fig. 17 (b) shows the results of the output working voltage of the bidirectional buck-boost converter, which when given 1000 W/m² of radiation. It can be studied more deeply that the bidirectional buck-boost converter output voltage using PI is already good and in a steady-state condition in 0.1s-1s seconds with an output voltage of 297.8 V. Whereas for Fuzzy, there are signs that in steady-state conditions are 0.29s-1s with a bidirectional buck-boost converter output voltage of 298.3 V. When compared to the output voltage of the bidirectional buck-boost converter using the PI and Fuzzy methods for the process to steady-state, the PI system is faster than the Fuzzy system with a time difference of 0.19s which can be seen from the graph above.

Table 8. Output Voltage of bidirectional buck-boost converter using Fuzzy Battery and PI Battery radiation 1000 W/m² at 1s

PI Battery	Fuzzy Battery	Time Difference for Steady State
V output	V output	Fuzzy(s) – PI(s)
297.8	298.3	0.19

V. Conclusion

In this research, focused on a comparative study between the PI and Fuzzy methods to see its effectiveness, the following conclusions are drawn:

1. The MPPT PI method produces a good and more stable boost converter output voltage in every radiation change made, while the boost converter output voltage controlled by the Fuzzy Logic method is less good and less stable in the radiation position of 1000 W/m² and radiation of 500 W/m² but irradiated. 100 W/m² of voltage has shown stability.
2. The result of the boost converter output voltage using Fuzzy Logic and PI methods entered the voltage range of 600 V with a very small difference in output voltage. At radiation 1000 W/m², the difference is 1.3 V, radiation 500 W/m², the difference is 0.4 V, and radiation 100 W/m², the difference is 0.1 V.
3. The results of the bidirectional buck-boost converter output voltage using the Fuzzy Logic and PI methods enter the 300 V voltage range with a very small difference in output voltage for PI Battery 297.8 V and Fuzzy Battery 298.3 V.
4. The output voltage of the bidirectional buck-boost converter PI is better, which is characterized by a faster steady-state condition in 0.1s-1s seconds with an output voltage of 297.8 V. Whereas for Fuzzy, the steady-state is 0.29s-1s with a bidirectional buck-boost converter output voltage of 298.3 V.

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