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Design MPPT with anfis method on zeta converter with DC load

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Abstract
Maximum power point tracking (MPPT) for PV (Photovoltaic) systems is provided in this research using artificial intelligence-based control. The design of MPPT system with Anfis Method on the Zeta Converter with DC Load is used to optimize the work of the Photovoltaic which will be used for DC load sources. The MPPT process consists of four main stages, namely module training data, determining input and output data, determining the number and type of membership functions and ANFIS training data. Zeta converter works like a buck boost, which can increase or decrease the voltage which is an advantage in designing systems with very volatile Photovoltaic sources. Zeta Converter is used to get higher efficiency, smaller input and output current ripple values and smaller core losses in the inductor. To improve the efficiency of system performance, An MPPT algorithm for the adaptive neuro fuzzy inference system (ANFIS) that is programmed into a microcontroller controls the zeta converter. ANFIS control is used because the response is faster and more effective. The combined simulation's findings demonstrate that the ANFIS control was successful, and the system can now produce the best possible power from Photovoltaic ipanelsiiniMPPT mode by boosting efficiency by up to 19.96%.

1. Introduction

Indonesia has abundant potential for fossil and non-fossil energy sources. However, referring to the energy security index, Indonesia's energy system is not well organized [1]. In 2013, for example, Indonesia was ranked 73rd out of 129 countries for the best energy management. This indicates that we have not reached the optimal level of energy consumption efficiency. In addition, currently most of the domestic energy needs are still dominated by the use of fossil energy sources such as oil, gas and coal. Based on this, the large potential of alternative energy sources, especially from renewable sources, forces the government to prioritize the development of new and renewable energy sources (EBT) [2]. The use of renewable energy is urgently needed. The use of renewable energy that will never run out, one of which is the use of the sun using photovoltaic [3].

A photovoltaic (PV) system's output power fluctuates with variations temperature and radiation. However, the maximum power point is a specific position on the PV characteristic curve (MPP). To maintain the PV at the Maximum Power Point, a technique known as the MPPT Algorithm is required. Whenever the weather is constantly shifting, this algorithm had to be capable of generating the most power. Maximum Power Point Tracking MPPT controller which continuously tracks the MPP of the PV module at all irradiations and temperatures [1] [4]. MPPT is an electronic system that must exist in a solar cell system so that the system can produce maximum power. This is so that the wasted voltage is not fully lost but is instead modified by maximizing the system's current output. MPPT (Maximum Power Point Tracking) can finds the maximum power point of the system to achieve this. The Design and Implementation of MPPT using a Zeta Converter for DC loads such as lights and water pumps which need different quantities of power are explored in this study. ANFIS control is used to maintain the converter's output voltage stability [5] [6]. The fundamental idea of basically all MPPT control systems is to produce optimized Duty Cycle (D) for DC-DC converters that allow the PV system work at Maximum Power Point (MPP), so greatly improving performance [7]. This ANFIS control utilizes the advantages of FLS and ANN to deal with fuzzy inference rules that lack self-learning capabilities, design according to expert experience, low control precision, weak robustness and real-time capabilities [8]. Thus, the ANFIS control is expected to be able to approach the desired results with smaller errors and have better efficiency than fuzzy controls [9] [10] [11]. This power setting is adjusted to the needs of DC loads in the garden in the form of lights and water pumps for watering plants.

By implementing the MPPT system using the ANFIS method with the maximum working power parameter of the Photovoltaic, thus bringing up the efficiency value for planning in saving electricity costs for garden lawn sprinkler water pumps and garden lighting lamps that have been using power from PLN and also make it easier to water the grass in the garden 12][13][14] whenever there is no PLN electricity supply. In addition, it can be an answer to the problem of energy use in the present and in the future.

2. Research Method

The design and use of the MPPT mechanism to maintaining stability are discussed in this paper. The Zeta Converter will receive the Photovoltaic output power and the system to be carried out is shown in Figure 1.

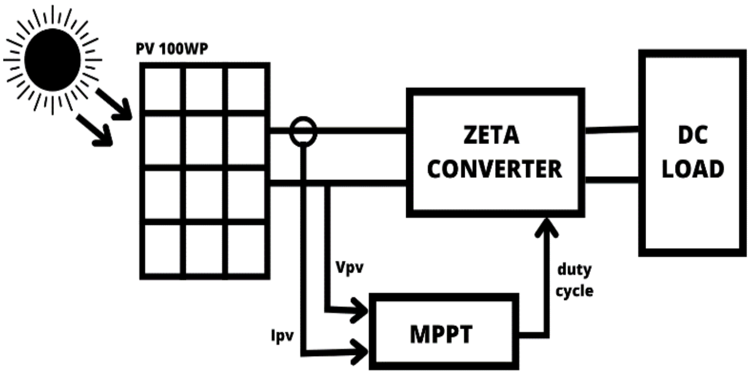

Figure. 1 Subsystems of the MPPT-ANFIS

The functioning of this system is illustrated in Figure 1, where Photovoltaics are shown as a source of electrical energy utilized to provide a load. To step up and step down the voltage to provide the load, a zeta converter is applied. Almost all MPPT control systems work on the concept of producing regulated Duty Cycle (D) for DC-DC converters, which helps the PV system perform at Maximum Power Point (MPP), improving efficiency through tracking speed and high fluctuations. Such that it can match the voltage needed by the load and is stable [15],[16]. The sensor output serves as both an input for data and a benchmark for the Photovoltaic power output when the duty cycle is set utilizing control (ANFIS) [17][18].

Photovoltaic power is the term used to describe the capacity of a Photovoltaic setup to produce current flowing through the load and voltage on the load. while optimizing the amount of power it generates when light hits the device. The current-voltage curve illustrates this capability (I-V). The fundamental idea is to regulate the flow of current between the open voltage point and the short circuit position behind producing the I-V curve of PV [19][20]. In this paper, 1 photovoltaics are used with 100-Watt power shown in Table 1.

Table 1. Photovoltaic Specification

Parameter	Value
Maximum Power	100W
Maximum Power Voltage	18 V
Maximum Power Current	5.56 A
Open Circuit Voltage	22.5 V
Short Circuit Voltage	6.17 A
Actual Operating Cell Temperature	45^{o}C+-2^{o}C
Maximum Sistem Voltage	1000 V_{dc}
Maximum Series Fuse	10 A
Weight	7.4 Kg
Dimension	1050*675*30mm
Standart Test Condition	25oC 1000 W/m^2

The non-linear photovoltaic output is affected by the temperature and irradiation. The I-V characteristics curve of PV is shown in Figure 2 while the P-V Characteristic curve shown in Figure 3 with difference irradiance.

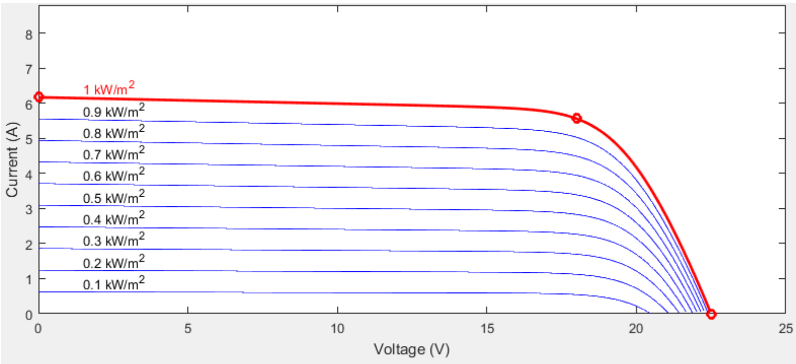

Figure. 2 I-V Characteristic at Irradiance Variation

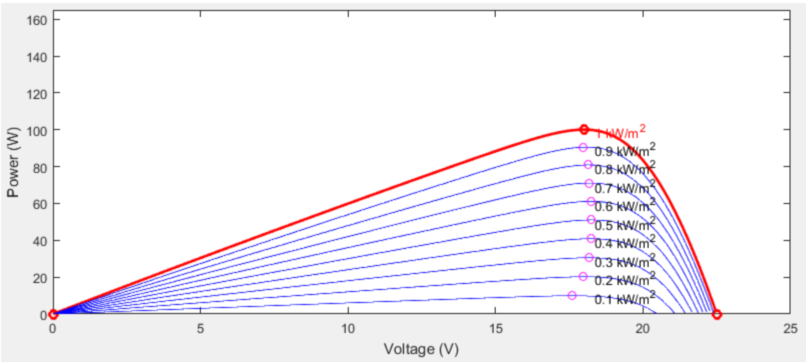

Figure. 3 P-V Characteristic at Irradiance Variation

2.1 Zeta Converter Modelling

From an input voltage whose output value fluctuates up and down, a positive output voltage is produced by the zeta converter topology. Two inductors are needed for zeta converters, as well as a flying capacitor in series [18][21].

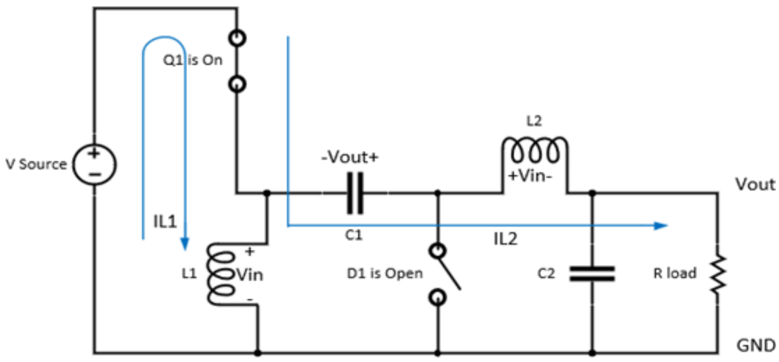

Figure 4. The On-Mode Circuit of Zeta Converter

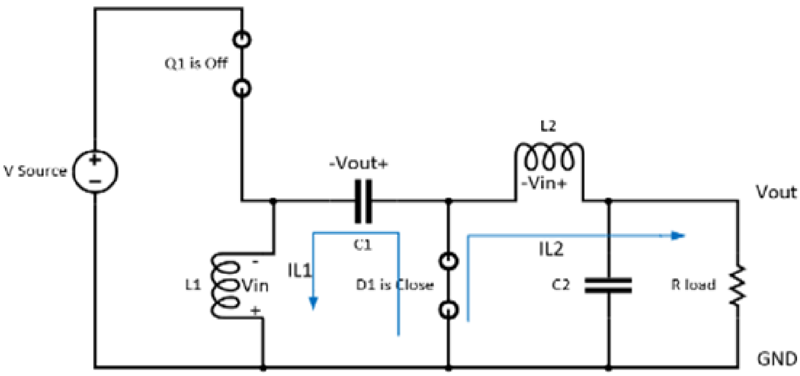

Figure 5. The Off-Mode Circuit of Zeta Converter

Figures 4 and Figure 5 illustrate that its zeta converter works at CCM when both Q1 and Q2 are turned off. When Q1 is active, as illustrated in Figure 4, In a non-conducting or reverse biased situation the diode D1 and both inductors L1 and L2 are in a charging state at this time. While inductor L2 is charged by capacitor C1, inductor L1 is charged by the input source voltage. Consequently, the current in both inductors grows linearly under these circumstances [20][21]. In the State Off position (Q1 is not active), the diode D1 is in the condition of forward bias or conduction, as shown in Figure 5. Under this circumstance, the capacitor C1 and the load will be used to discharge the inductors L1 and L2. As a result of inductor discharge, the current from both inductors will drop.

Table 2. Zeta Parameters

Parameters	Value
Input Voltage (V_{in})	18 V
Output Voltage (V_{out})	14 V
Input Current (I_{in})	5,56 A
Output Current (I_{out})	3 A
Ripple Current	5 %
Ripple Voltage	0.1 %
L1 and L2	210,64 uH
Frequency	40 kHz
Power	100 W

The parameters from Table 1 were determined using the following Equation 1, Equation 2, Equation 3, Equation 4, Equation 5, Equation 6, Equation 7, Equation 8, and Equation 9.

$$D = \frac{Vout}{Vout + Vin} \tag{1}$$

$$\Delta_{IL1(pp)} = 20\% \times Iin \tag{2}$$

$$L_{1a} \frac{Vin \times D}{\Delta IL1(pp) \times Fsw} \tag{3}$$

$$L_{1b} \frac{Vin \times D}{\Delta IL2(pp) \times Fsw} \tag{4}$$

$$I_{L1a} = I_{in} + \frac{\Delta IL1}{2} \tag{5}$$

$$I_{L1b} = I_{out} + \frac{\Delta IL2}{2} \tag{6}$$

$$Cout_{(min)} \frac{D}{8 \times \Delta Vo \times Fsw} \tag{7}$$

$$Cin_{(min)} \frac{D \times Iout}{Vin \text{ x } \Delta Vcin \text{ x } Fsw} \tag{8}$$

$$Cc_{(min)} \frac{D \times Iout}{Vout \times \Delta Vcc \times Fsw} \tag{9}$$

Where :
Vin = Input voltage (V)
Iin = Input current (A)
Fsw = Frequency switching (kHz)
Vout = Output voltage (V)
ΔIL = Ripple inductor current
D = Duty cycle

2.2 ANFIS Controller Modeling

Artificial neural networks and fuzzy logic systems are combined to create neuro-fuzzy. A fuzzy inference system that is educated using a learning algorithm generated from an artificial neural network system serves as the foundation of the neuro-fuzzy system. The neuro-fuzzy system therefore has all the benefits that the artificial neural network system and the fuzzy inference system have [22][23]. The term "ANFIS" is widely used to describe the neuro-fuzzy system due to its capacity to learn (adaptive neuro fuzzy inference system). ANFIS in this study was used as a controller for MPPT. The input used in ANFIS consists of 2 pieces, namely error (e) and error difference (Δe). The resulting output is the duty cycle value. Like the Artificial Condition Network, ANFIS needs to be given training in advance using input-output data pairs. Figure 6 illustrates ANFIS structure Model. The Takagi-Sugeno-Kang fuzzy inference model is the fuzzy inference system used in the Artificial Neuro Fuzzy Inference System (ANFIS) for this structure [24]. Fig 7 represents Flowchart structure of an ANFIS -based MPPT control, which was created using the MATLAB/Simulink design program.

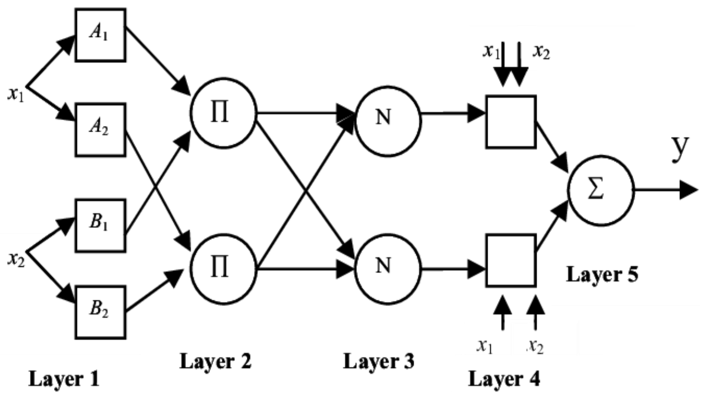

Figure 6. ANFIS Structure Model

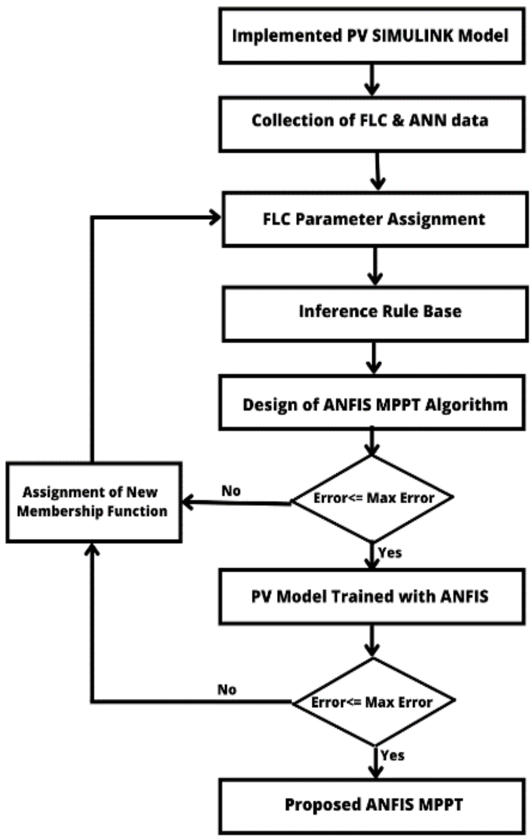

Figure 7. Flowchart structure of an ANFIS -based MPPT control

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There are five levels of processes in the Neuro-Fuzzy system, and each layer's equations and functions are described as follows Equation 10.

Layer 1: Fuzzyfication

Let O1,i represent output from each layer 1 node. Node I is a variable node in this layer using a call node O1,i = Ai(x) for I = 1, 2; or O1,i = Bi(y) for I = 3, 4.

$$f(x,a,b,c) = \frac{1}{1 + (\frac{x-c}{a})^{2b}} \tag{10}$$

Parameter c is located in the middle of the curve. As an expression, the Gaussian membership function is Equation 11.

$$e^{A(x) = \frac{(x-c)^2}{2a^2}} \tag{11}$$

Layer 2: Product Layer

The node function is the prod t-norm for each node in layer 2. This layer multiplies all incoming signals and sends out the results once layer 1 has synthesized the information transfer. The product layer's output is represented as follows Equation 12.

$$o_{2,i} = \mu Ai(x) \times \mu Bi(y) = Wi \tag{12}$$

Layer 3: Normalization Layer Each node.

In layer 3, that was obtained from the preceding product layer. The output is based on Equation 13.

$$o_{3,i} = \frac{W_i}{W_1 + W_2} \tag{13}$$

Layer 4: Node Defuzzification Layer

A natural adaptation is present at this layer. The following Equation 14 is used to determine this layer's defuzzification output.

$$o_{4,i} = O3, i(\alpha 4, i = O3, i(\alpha ix) + \beta iy + yi \tag{14}$$

Layer 5: Layer Total Output Single Node

The following Equation 15 fixed function is used at this layer to synthesize the data sent via layer 4 and return the whole output.

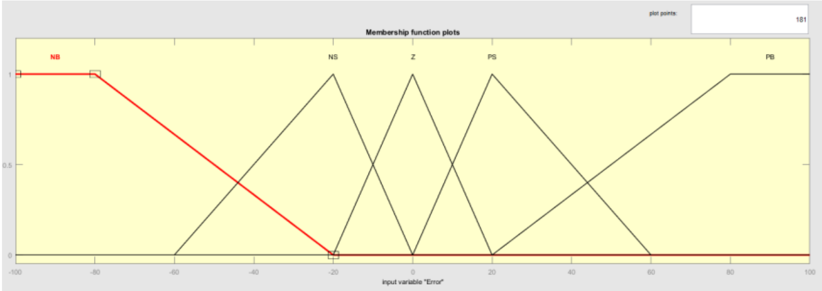
$$o_{5,i} = \frac{\sum W_i Y_i}{\sum} \tag{15}$$

The input variable for MPPT control is obtained from the *Photovoltaic* output power. The ANFIS training data used in both controls were obtained from simulation results using the Fuzzy algorithm [26].

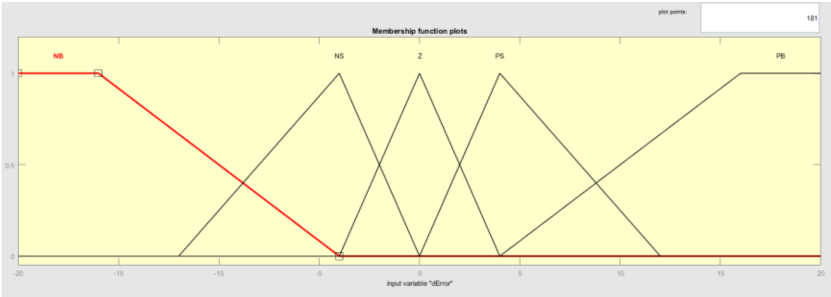
2.3 Maximum Power Point Tracking Design

The MPPT system consists of a DC-DC converter currently based between the Photovoltaic and the load that is regulated by an algorithm to adjust the power converter's duty cycle value in order to obtain the highest output voltage and current at a specific level of solar radiation and temperature [25].

The process of tracking the maximum power output of the solar panel using the ANFIS algorithm begins by sensing the current and voltage of the Photovoltaic output. Then the calculation of the value of the Photovoltaic output power will be carried out. MPPT-ANFIS control input is the value of slope S(t) and change of slope ΔS(t)[20]. The result of dividing the value of P by V is called the slope. To achieve the MPP value, the slope value =0[21], [26]. The proportion of P to V determines the slope's orientation. The parameters of the converter being utilized will influence the duty cycle's orientation. If the result of the comparison (slope) produces a positive value, the duty cycle value is increased, and if it produces a negative value, the duty cycle value is reduced. The data slope S(t) in this research is 5 triangular membership functions used to represent the input slope value shown in Figure 8.



(a)



(b)

Figure 8. (a) Membership Function of Input Error (b) Membership Function of Input dError

Input change of slope ΔS(t) is obtained from the difference between the current slope value and the previous slope value. Figure 8(a) displays the membership function of input Error, the input change of slope S(t) with triangular and trapezoid membership functions. The ANFIS controller will next process the two inputs as illustrated in Figure 8(b) displays the membership function of input delta Error to determine the value of the change in duty cycle (dDuty) in accordance with the MPP conditions at a specific irradiation value and temperature.

3. Results and Discussion

In the ANFIS MPPT system, there are four conceptual stages that must be met, including: Module training data, determining input and output data, determining the number and type of membership functions and ANFIS training data. In the Training data module itself is used to collect the highest Voltage, Current and Power values from the Solar Panel and then set tracking parameters such as Vmpp and Impp [26]. Determining the input data used in ANFIS consists of 2 pieces, namely error(e) and error difference(Δe). The resulting output is the duty cycle value. Determining the number and types of membership functions and fuzzy rules are used as data to be trained to test whether MPPT ANFIS meets the criteria for optimization. Training data by ANFIS will produce a small error. The output of anfis is the duty cycle. When the duty cycle is corrected, the output power will be close to the set point power. If the power is appropriate then the process is complete if it is not appropriate then it will calculate the error and delta error again [27].

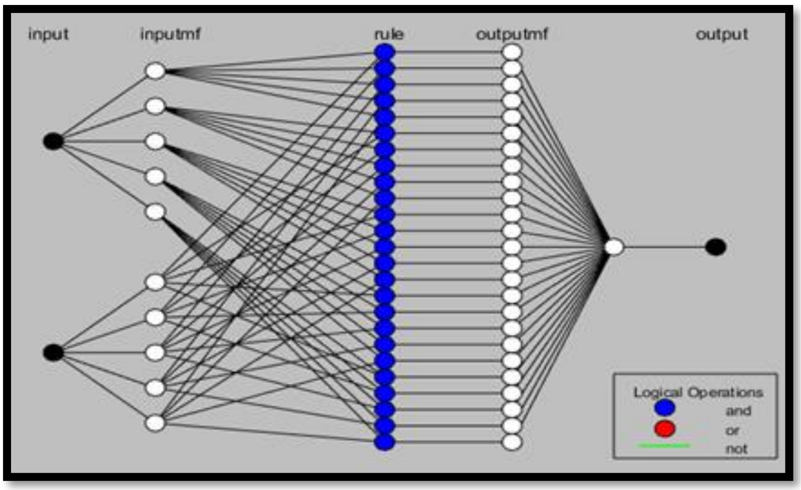


Figure 9. Sructure of an ANFIS System

According to Figure 9, the initial layer of the structure, an ANFIS system with seven levels, takes input from each period in a process known as "fuzzification". The 2 and 3 layers is inference engine process (fis) using fuzzy rules for the calculation procedure A fourth layer down, After training the data, fuzzy membership will be automatically formed in the input, output and rule base. The membership function is chosen in such a way that the training results have the smallest error. The type of input membership function used is the Triangle type with 5 pieces for each input. After training, the form of the input membership function with optimized parameters is obtained. After the training has been completed, ANFIS is ready to be used for the inference process. Finally, all the output from the layers in ANFIS will be summed up and the inference results will be obtained in the form of a duty cycle.The defuzzification process is then performed using the weight average technique, and the fuzzy results are then calculated into crisp output.[24]. The EBP method additionally implements a backward flow that requires updating the ANFIS parameters by doing an error computation at each layer. For FLC and ANFIS simulation tests, which are performed using one 100Wp PV to power the system, the MATLAB software simulation is utilized. The battery, which has a capacity of 12 V, 20 Ah, is then implemented as a load to deliver power from the PV. Figure 10 illustrates the experimental circuit drawing. Using duty, error, and delta error data, performance analysis was used to moment analyze the FLC settings. Learn about more ANFIS controller settings by studying test and training mistakes as well as training data.

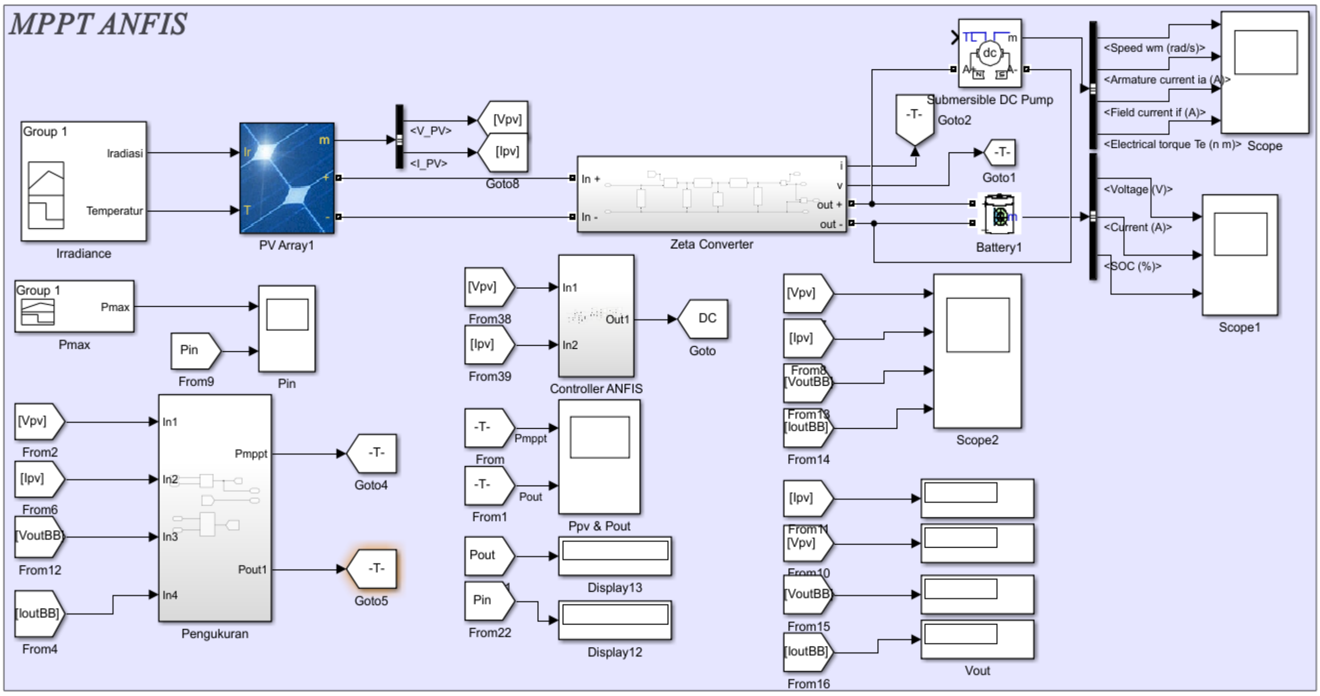


Figure 10. Simulation of Zeta Converter with ANFIS

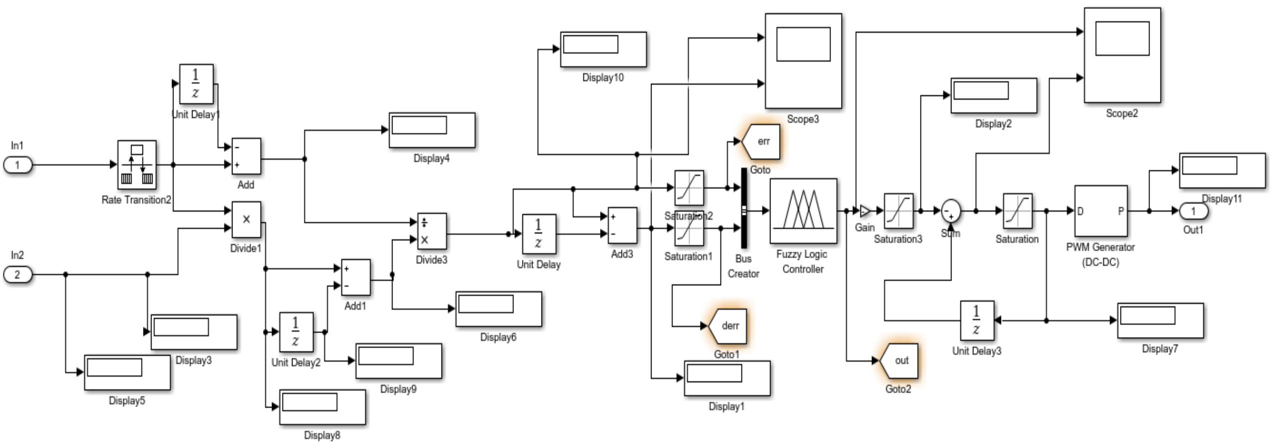
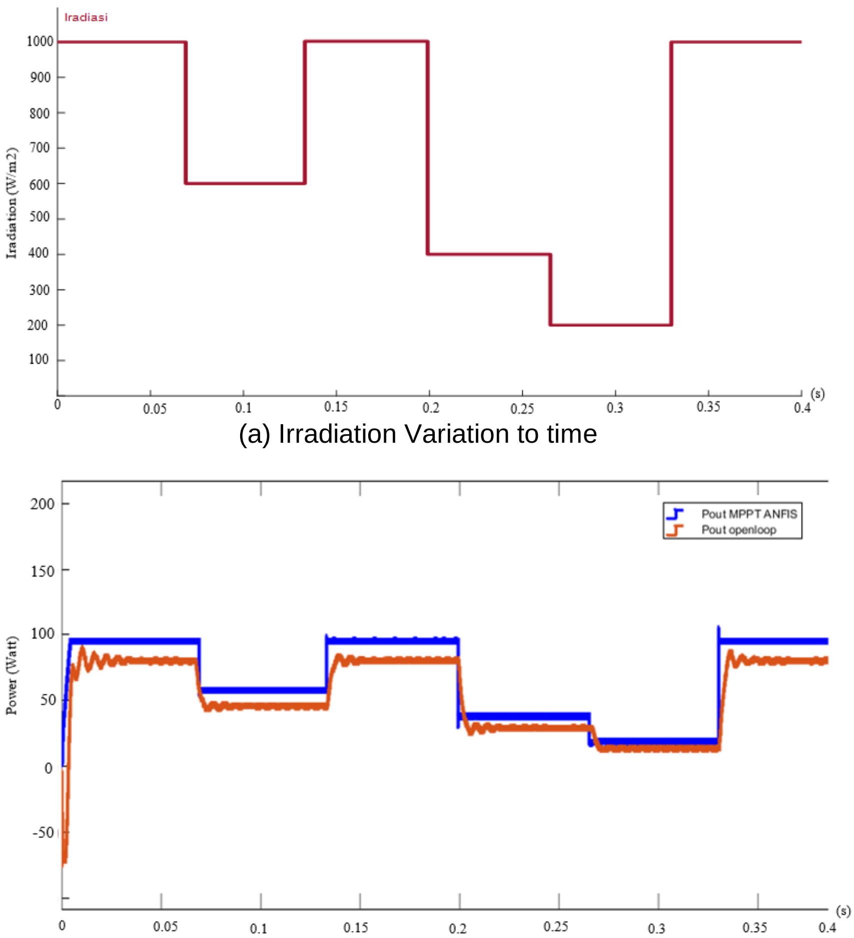


Figure 11. Controller ANFIS on Simulink MATLAB

Simulations were carried out with variations in irradiation values, namely at 1000 W/m2, 600 W/m2, 400 W/m2, dan 200 W/m2. Figure 11 is a Controller ANFIS on Simulink MATLAB, while Figure 10 is a Simulation of Zeta Converter with ANFIS. MPPT-ANFIS control will then be compared with a system without MPPT control to find out the performance of MPPT control in improving the efficiency of using Photovoltaics. To find out the work of the control system used by MPPT ANFIS, it is necessary to test it with varying irradiation conditions according to environmental conditions. The test was carried out using 1 solar panel assembled and connected to a zeta converter. Where the output of this zeta converter will be used for DC load. Then the close loop test to obtain the maximum power value is carried out by comparing the maximum power results from the characteristic test (openloop) with the tracking duty results obtained when approaching the maximum power. Figure 13(a) below shows the power response processed by the Adaptive Neuro Fuzzy Inference System algorithm with changes in irradiation from high to low and back to high. With this change in irradiation, MPPT ANFIS can achieve optimum power values and work in conditions that vary in real terms.



(a) Irradiation Variation to time

(b) Output Power of ANFIS based MPPT to time

Figure 13. Output Power Response of MPPT-ANFIS and Openloop on Variable Irradiance

Table 3. ANFIS based MPPT-ANFIS Simulation Result

Pout (Watt)	Irradiance (W/m2)	Pout Openloop (Watt)	Pout MPPT ANFIS (Watt)
100	1000	80.46	95.76
	600	46.57	58.55
	1000	80.09	96.08
	400	29.13	39.05
	200	14.23	18.84
	1000	79.98	95.36

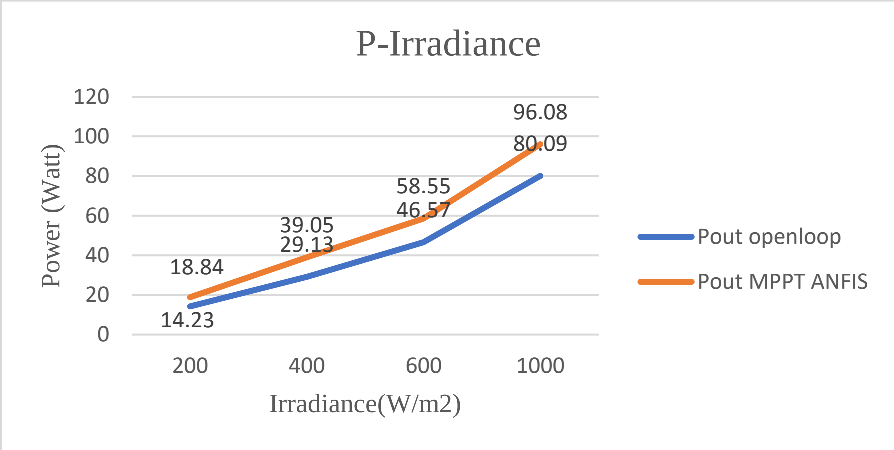


Figure 14. Power Comparison in Various Irradiance

The MPPT mode can supply the dc pump under low irradiation conditions and increase the efficiency of using Photovoltaics up to 19.96%. This is obtained from the calculation below Equation 16.

$$Efficiency = \frac{P_{mppt} - P_{openloop}}{P_{openloop}} \text{ x } 100\% = \frac{96.08 - 80.09}{80.09} \text{ x } 100\% = 19.96\ \% \quad (16)$$

Table 3 shows the output power response data when the MPPT-ANFIS control is working. According to the simulation's findings, between 400 and 600 W/m2 of irradiation, then the MPPT control will work to get the maximum input power value that can be generated by Photovoltaics to supply the load, when the input irradiation is 200 W/m2 power used to supply the load is 18.84 Watt. When the input irradiation is 400 W/m2 power used to supply the load is 39.05 Watt. When the input irradiation value is 600 W/m2, the power used to supply the load is 58.55 Watt. When the irradiation is 1000 W/m2, the ANFIS works to give output power value of the Zeta Converter so that it does not exceed the load requirement, namely with an output power of 96.08 Watts. The system created can supply DC pumps even at an irradiation value of 200 W/m2.From the Figure it can be concluded that if the duty cycle value remains, the zeta converter can maximize the power that comes out of the Photovoltaic itself.

4. Conclusion

This study provides a modeling analysis of the output characteristics of the photovoltaic power system in order to increase the conversion efficiency of solar cells and enable it to operate at its maximum power point. Experimental research into the performance analysis of a 100 W ANFIS regulated is done in this work. The suggested system's performance is evaluated under various Irradiation settings and shown to be effective with outstanding steady-state and dynamic performance, thus confirming the design of the system. When the input is variable, adaptive neurofuzzy inference systems (ANFIS) are useful for managing the output power. From this research, it can be concluded that power varied. The ANFIS Controller can create a higher Photovoltaic output power of 96.08 Watt, and the MPPT mode can provide dc pumps in low irradiation situations and increase the efficiency of Photovoltaic usage by up to 19.96%, as can be seen in the result.

Notation

V_{in} : Input Voltage of Zeta Converter
$f_{switching}$: Switching Frequency
V_{out} : Output Voltage of Zeta Converter
L : Inductor
C : Capacitor
W_p : Wattpeak
R_{load} : Resistor Value of Load
P_{out} : Output Power

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