INTEK Jurnal Penelitian
Vol. 9, No. 1, pp. 49-57, April 2022

Comparison of ANFIS and FLC as Charging Battery Based on Zeta Converter

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***Abstract*— Solar energy is an unlimited source of energy and its availability will never run out. It can be converted into a supply of electrical energy and saved into battery through converter. There are many people who convert solar energy into electrical energy. Unfortunately, when stored in the battery, it is still necessary to adjust the output voltage of the converter. Therefore, it is required a controller to do it. To solve the problem, in this paper, a Fuzzy Logic Controller (FLC) and an Adaptive Neuro Fuzzy Inference System (ANFIS) control is proposed to adjust output voltage while the input voltage is fluctuate. These two controllers are compared to investigate the better response. The constant voltage method is applied and after ran the simulation, it obtained that ANFIZ giving better response than FLC. This occurs due to setting point obtained faster when using ANFIZ. The result, it need time 0,04s to get setting point on output voltage**

***Keywords*— Solar energy, Charging, FLC, ANFIS.**

I. Introduction

Indonesian people are very dependent on PLN's electricity supply, in addition to lighting needs as well as to support economic activities. PLN still relies on fossil fuels to produce electricity. There are many other resources to reduce or replace fossil fuels that have not been utilized optimally such as hydro, geothermal, mini/micro-hydro, biomass, solar, wind and uranium resources [1].

From this, it can be said that the distribution of electrification in Indonesia is still very low, where many areas are electrified due to the location of the area which is difficult to reach by sources of electricity supply, so that one of the shortages of lighting for residential homes also has an impact on economic development in the area [2]. Judging from its geographical location, Indonesia is a tropical country so it has great potential as a producer of alternative energy sources, namely solar energy. Solar energy is an unlimited source of energy and its availability will never run out and this energy can also be used as alternative energy that will be converted into electrical energy, using solar cells [3]. One problem that arises with the use of solar energy is that the energy produced varies depending on the season, time of day and environment. This will be especially felt in areas where the intensity of the sun varies in an extreme way [4], [5]. Therefore, an energy storage system is needed, namely a battery. To prevent damage to the battery, a controller is needed, known as a charge controller. The main function of the charge controller is to maintain the state of the battery by preventing excessive current and voltage distribution in the battery [6]-[7]. Based on the problems above, previous research has been made that discusses battery charging with Fuzzy Logic control[8], but this time the author compiles a new article, namely a battery charging device with Adaptive Neuro Fuzzy Inference System (ANFIS) control. The use of ANFIS control is expected to reduce errors or increase data accuracy which is high compared to Fuzzy Logic control [9], and this system uses a zeta converter which is very suitable, because it has voltage ripple and current ripple as well as good efficiency compared to other converters [10]. This system utilizes solar energy as a source of electrical energy. However, the output from the solar panel is not always stable because it depends on the

DOI : http://dx.doi.org/10.31963/intek. v9i1.3410

weather in the environment, so a converter is needed as a regulator of the output voltage of the solar panel, so that it can be adjusted according to the desired battery charging needs [11]. The energy generated by the solar panels is used to charge the battery using ANFIS control, the converter output voltage will be adjusted according to the setpoint for the charging process of around 14.4 Volts.

II. Research Methodology

This paper discusses the comparison of the FLC and ANFIS methods to keep the output voltage stable as battery charging determined by the Zeta Converter output, and then the system that will be conducted later is shown in Figure 1.

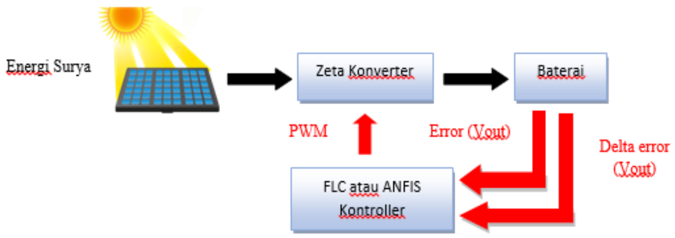

Figure 1. The Overall Methods of System

In Figure 1 it is explained that the workings of this system are solar panels which are a source of electrical energy used to charge the battery. Zeta converter is used as a step up and step down voltage to supply the battery. In order for the voltage to charge the battery to be stable and make maximum use of the solar panel output, the duty cycle of the zeta converter must be regulated in such a way, so that it does not fluctuate and can match the voltage required by the battery. Control (ANFIS) or FLC is used to set the duty cycle, where the sensing output will be used for input data as well as a reference to the charging voltage set point for the battery.

A. Photovoltaic

The electrical power generated by the solar panel when it gets light obtained from the ability of the solar panel device is used to produce voltage on the load and current through the load at the same time. This ability is represented in the current-voltage curve (I-V). The basic principle for measuring the I-V curve of PV is based on controlling the current provided between the short circuit point and the open voltage point [12]. The characteristics of the I-V and P-V curves on the solar panel are shown in Figure 2.

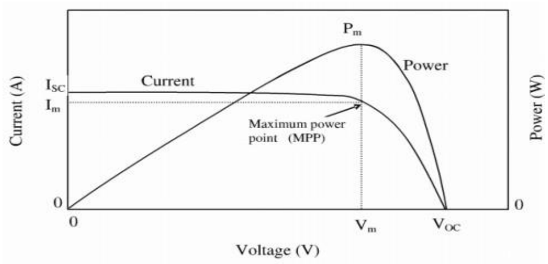

Figure 2. characteristics I-V, and P-V

Description in Figure 2:
Isc : Short circuit current
Voc : No-load voltage
Vm : Maximum voltage
Im : Maximum current

I-V and P-V curves Figure 2. which illustrates the state of a solar panel operating normally. The solar panel will produce a maximum value if the values of Vm and Im are also maximum. While Isc is the maximum electric current at the value of volts = zero. Voc is the maximum volt at zero current value, Voc increases logarithmically with increasing sunlight [13].

B. Zeta Converter Modeling

The zeta converter topology provides a positive output voltage from the input voltage whose output voltage varies up and down. Zeta converters require two inductors and a series capacitor, usually called a flying capacitor [14].

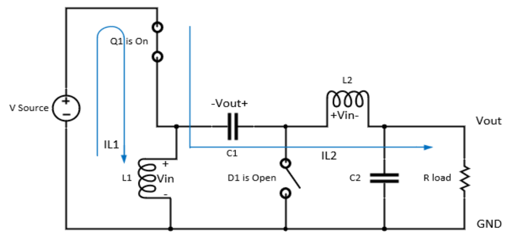

Figure 3. The On-Mode Circuit of Zeta Converter

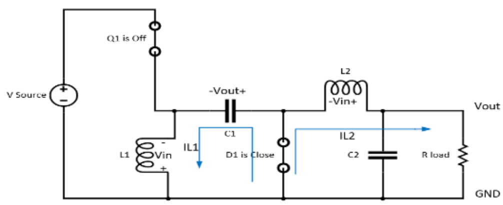

Figure 4. The Off-Mode Circuit of Zeta Converter

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Figure 3 and Figure 4 show that the zeta converter operates at CCM when Q_1 is “On” and when Q_2 is “Off”. In the On State condition (Q_1 is active) shown in Figure 3 makes the diode D_1 in a reverse biased or non-conducting state, in this condition both inductors L_1 and L_2 are in a charging state. Inductor L_1 is charged from the input source voltage while inductor L_2 is charged from capacitor C_1. So that, in this conditions the current in both inductors increases linearly [15]-[16]. As for the State Off condition (Q_1 is not active) which is shown in Figure 4 making the diode D_1 in a forward bias or conduction condition, in this condition the inductors L_1 and L_2 will be discharging through the capacitor C_1 and the load. Therefore the current from both inductors will decrease due to inductor discharging.

Table 1. Zeta Parameters

No	Parameter	nilai
1	$V_{s(min)}$	18.24 V
2	$V_{s(max)}$	21.8 V
3	Arus Input (I_{in})	11.12 A
4	Tegangan Output (V_{out})	14,4 V
5	Arus Output (I_{out})	6,75 A
6	Frekuensi Switching (Fs)	40 Hz
7	Ripple $Vout$(ΔVo)	25 mV
8	Voltage Ripple Cin (ΔVCin)	1 %
9	Voltage Ripple $Cout$(ΔVcc)	1 %

From Table 1, the parameters obtained using the following equation:

$$D = \frac{Vout}{Vout + Vin} \quad (1)$$

$$\Delta I_{L1(pp)} = 20\% \times Iin \quad (2)$$

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

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

$$I_{L1a} = I_{in} + \frac{\Delta IL1}{2} \quad (5)$$

$$I_{L1b} = I_{out} + \frac{\Delta IL2}{2} \quad (6)$$

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

$$Cin_{(min)} = \frac{D \times Iout}{Vin \times \Delta Vcin \times Fsw} \quad (8)$$

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

V_{in} = Input voltage
V_{out} = Output voltage
I_{in} = Input current
F_{sw} = Frequency switching
Δ_{IL} = Ripple inductor current
D = Duty cycle

C. Fuzzy Logic Modeling

In designing the control system so that ANFIS can run well, ANFIS requires a lot of data as input data and targets to be achieved. Therefore, the design of the neuro-fuzzy controller includes 4 stages, identification, fuzzification, determination of the rule base, and deffuzification [17], [18].

1. Determination of fuzzy input and output (Identification)

The first step in fuzzy design is to determine input parameters that can affect system performance. The input of the fuzzy controller is the output voltage of the zeta converter, and the fuzzy output is the duty cycle which is used to adjust the size of the output voltage of the zeta converter [19].

Setpoint CV = 14.4 volts
Error = -14.4 to 14.4
Delta Error = -17.28 to 17.28

2. Change the real value to the form of a fuzzy variable (Fuzzification)

The pre-determined input data (crisp) in the form of errors and delta errors are transferred to a fuzzy set to be used in calculating the truth value of the premise in each rule. This stage takes crisp values and determines the degree to which these values are members of each appropriate fuzzy set. Input and output variables are shown in Figure 5.

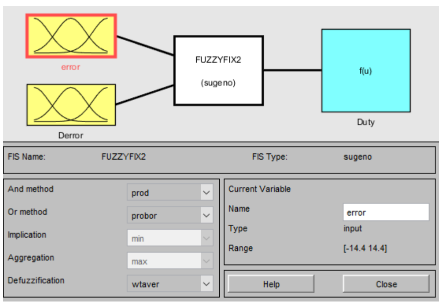

Figure 5. Variable input and variable output

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3. Determination of the rule base

In the Fuzzy Inference System there are basic rules or rule bases that are used to process the results of the fuzzification process. The rule base is a combination of the fuzzification process relationship between input variables. The basic rule functions to connect input and output with an if - then structure and is applied to the output with the AND operator [20]. Then determine the degree of membership of the set by utilizing the neural network by training data from the Zeta Converter close loop. In this process, 49 rules will be generated from the number of membership functions (mf) as shown in Table 2.

Table 2. Rule Base Fuzzy

De\E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

4. Fuzzy return to real value form (defuzzification)

The deffuzification process is used to convert the fuzzy variable back into a real variable, or in other words, the fuzzy control action which is still a set is converted into a single real value. The output of each given rule is linear with the input variable. This defuzzification process has the aim of finding the crunch value of the computation.

C. ANFIS Controller Modeling

Neuro-fuzzy is a combination of two systems, namely fuzzy logic systems and artificial neural networks. The neuro-fuzzy system is based on a fuzzy inference system that is trained using a learning algorithm derived from an artificial neural network system. Thus, the neuro-fuzzy system has all the advantages possessed by the fuzzy inference system and the artificial neural network system. From its ability to learn, the neuro-fuzzy system is often referred to as ANFIS (adaptive neuro fuzzy inference system)[21]-[22]. One form of structure that is well known is as shown in Figure 6. In using the Artificial Neuro Fuzzy Inference System (ANFIS) for this structure, the fuzzy inference system applied is the Takagi-Sugeno-Kang fuzzy inference model.

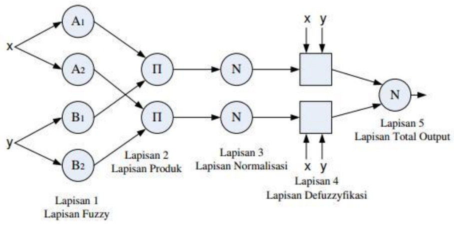

Figure 6. ANFIS Structure

In the Neuro-Fuzzy system there are five layers of processes in which the functions and equations of each layer are explained as follows [23], [24]:

Layer 1: Fuzzyfication

Let O_1,i be the output of each node in layer 1. Each node i in this layer is an adaptive node with the function node O1,i = Ai(x) for i = 1, 2; or O_1,i = Bi(y) for i = 3, 4, where x is the input to node i and Ai is the linguistic label (small, large, and so on) that corresponds to the function of this node. Elsewhere, O_1,i, the membership function of the Bell form is expressed by: is the membership function of A_1 and the degree of membership is specific for a given x that is sufficient to quantify Ai[25]. The membership functions that are widely used are the Bell and Gaussian forms [25].

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

With parameter b is usually positive. Parameter c is located in the middle of the curve. The Gaussian membership function is expressed by:

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

Layer 2: Product Layer

Each node in this layer consists of the prod t-norm operator as a node function. This layer synthesizes information transmission with layer 1 and multiplies all incoming signals and sends products out. The output of the product layer is expressed by:

O2,i = µAi (x). µBi (y) = Wi (12)

Layer 3: Normalization Layer Each node.

In this layer normalize the weight function obtained from the previous product layer. The normalized output is calculated by:

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$$O_{3,i} = \frac{W_i}{W_1+W_2} \quad (13)$$

Layer 4: Node Defuzzification Layer

At this layer is a natural adaptive. The defuzzification output of this layer is calculated by the formula:

$$O_{4,i} = O_{3,i}\ (\alpha_{4,i} = O_{3,i}\ (\alpha_i x) + \beta_i y + \gamma_i\ ) \quad (14)$$

Layer 5: Layer Total Output Single Node

At this layer it synthesizes the information transmitted with layer 4 and returns the entire output using the following fixed function:

$$O_{5,i} = \frac{\sum W_i Y_i}{\sum} \quad (15)$$

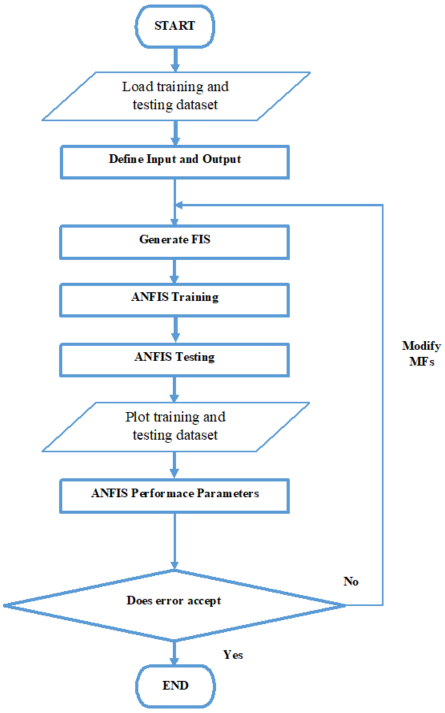

Figure 7. ANFIS flowchart design

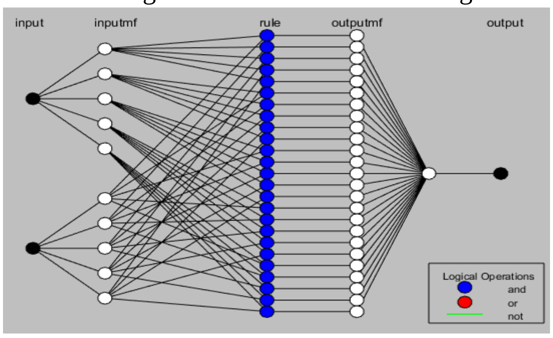

Figure 8. Structure of an ANFIS system

From Figure 8, the structure is an ANFIS system consisting of seven layers, the first layer is obtained input from each period which is called the fuzzification process. While the second and third layers are carried out by the inference engine process (fuzzy inference system) with fuzzy rules for the calculation process. Then in the fourth layer, the deffuzification process is carried out with the weight average method which is processed by the calculation of transforming the fuzzy results into the form of crips output, at this layer LSA calculations are also carried out to obtain the consequent parameter values. In the last or seventh layer, a summary process is carried out from the output in the fourth layer. In addition, there is also a backward flow, this process is carried out by the EBP algorithm, where at each layer an error calculation is carried out to update the ANFIS parameters.

The results of plotting training data are shown in Figure 9 and Figure 10 shows the results of the output data. This data is the value of the duty cycle resulting from the ANFIS training that has been tested, it can be seen that the red dot (the result of the ANFIS training) has entered exactly the blue circle which is the data center point.

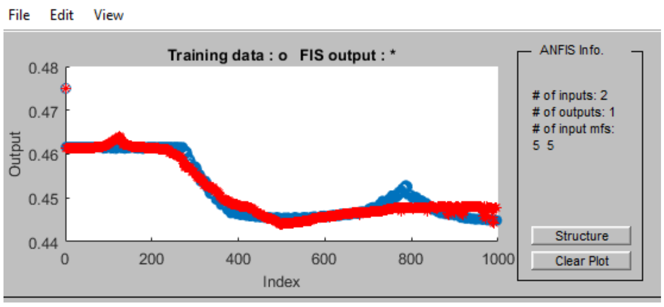

Figure 9. Result of ANFIS testing

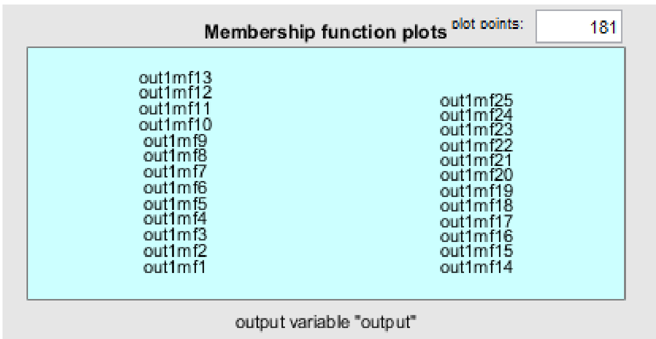

Figure 10. Result Output Data ANFIS

DOI : http://dx.doi.org/10.31963/intek. v9i1.3410

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III. Results and Discussion

The MATLAB software simulation is used for FLC and ANFIS simulation tests, which are carried out using 2 PV to supply the system, where the value of each PV is 100Wp and the configuration is 2 parallel, Then the battery is used as a load to supply power from the PV where the battery is used i.e. with a capacity of 12 V, 45 Ah. The experimental circuit drawing is shown in Figure 11. Performance analysis was carried out on a time compulsive basis to study the FLC parameters from the error, delta error and duty data. Also learn about ANFIS controller parameters from training data, training errors and test errors.

Table 3. Result of simulation with FLC

Suhu (°C)	Iradiasi (W/m²)	SOC Baterai (%)	Vin (V)	Vch (V)	Time Response System	Ich (A)
25	600	40	19,95	14,39	0.051 s	1,75
		50	19,96	14,38		1,4
		60	19,98	14,39		1,11
		70	19,97	14,38		1,06
		80	19,99	14,38		1,021
	700	40	20,93	14,34	0.051 s	1,85
		50	20,95	14,39		1,37
		60	20,94	14,38		1,21
		70	20,96	14,38		1,1
		80	20,9	14,38		1,151
	800	40	21,61	14,4	0.05 s	1,9
		50	21,62	14,41		1,55
		60	21,1	14,39		1,23
		70	21,09	14,38		1,2
		80	21,01	14,38		1,01

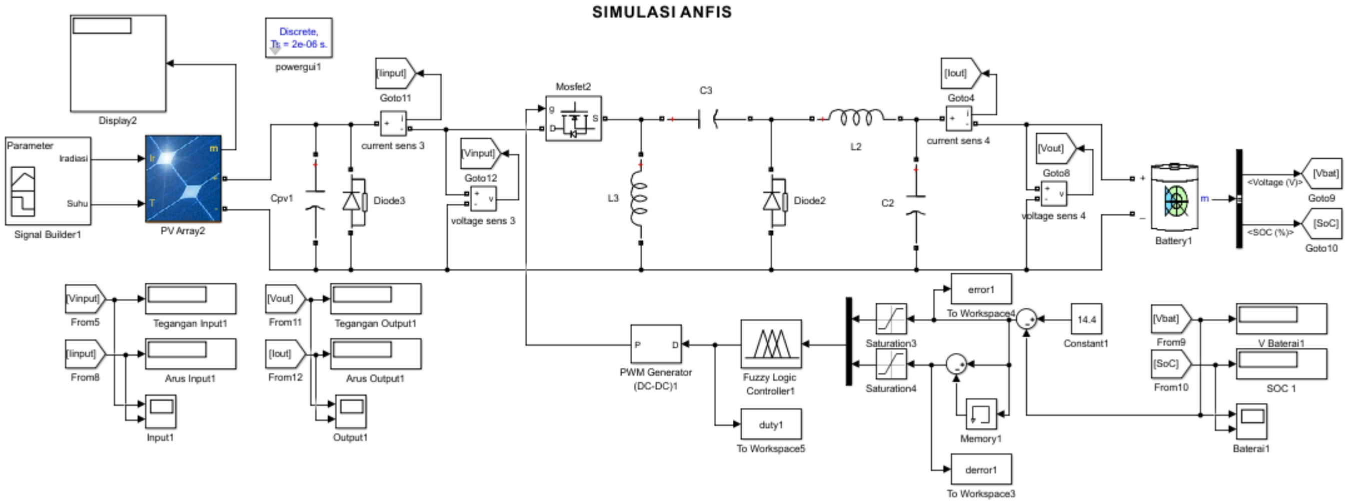

Figure 11. Simulation of Zeta Converter

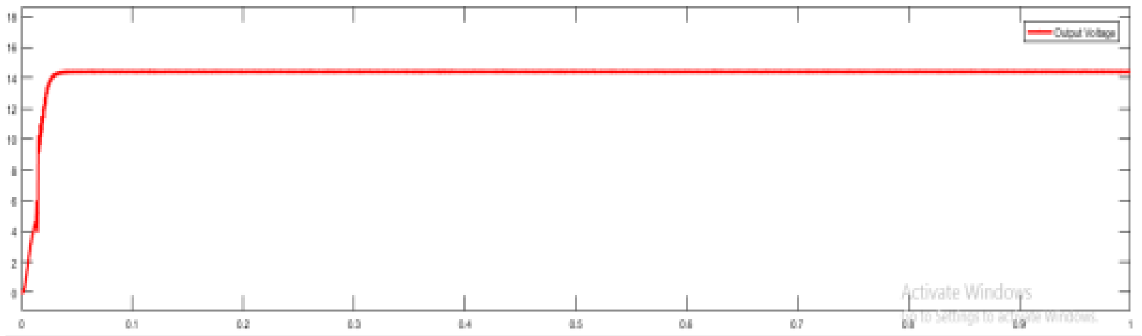

Figure 12. FLC simulation result wave in irradiation 800 (W/m²)

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Table 4. Result of simulation with ANFIS

Temp (°C)	Irradiance (W/m²)	SOC Battery (%)	Vin (V)	Vch (V)	Time Response System	Ich (A)
25	600	40	19,96	14,39	0.04 s	1,81
		50	19,97	14,38		1,4
		60	19,98	14,38		1,17
		70	19,97	14,38		1,073
		80	20,02	14,44		1,021
	700	40	20,97	14,39	0.04 s	1,8
		50	20,96	14,38		1,32
		60	20,99	14,38		1,2
		70	20,98	14,39		1,081
		80	20,9	14,44		1,01
	800	40	21,1	14,39	0.04 s	1,83
		50	21,08	14,38		1,42
		60	21,1	14,38		1,2
		70	21,09	14,38		1,071
		80	21,01	14,44		1,01

From the result, it can be seen that ANFIS and FLC can keep the voltage constant even though the input varies. From Figure 14, when irradiation 800 (W/m²) the results of the wave can be seen that the difference between two controls used. Although ANFIS rest time is slower than fuzzy, but the time to reach the set point is faster by used ANFIS control. It need time 0.04 s to reach the set point, while FLC takes 0.05 s to reach the set point

Table 5. Comparison Response System ANFIS and Fuzzy

Controller	Time Response System (10^{-2})
FLC	5 s
ANFIS	4 s

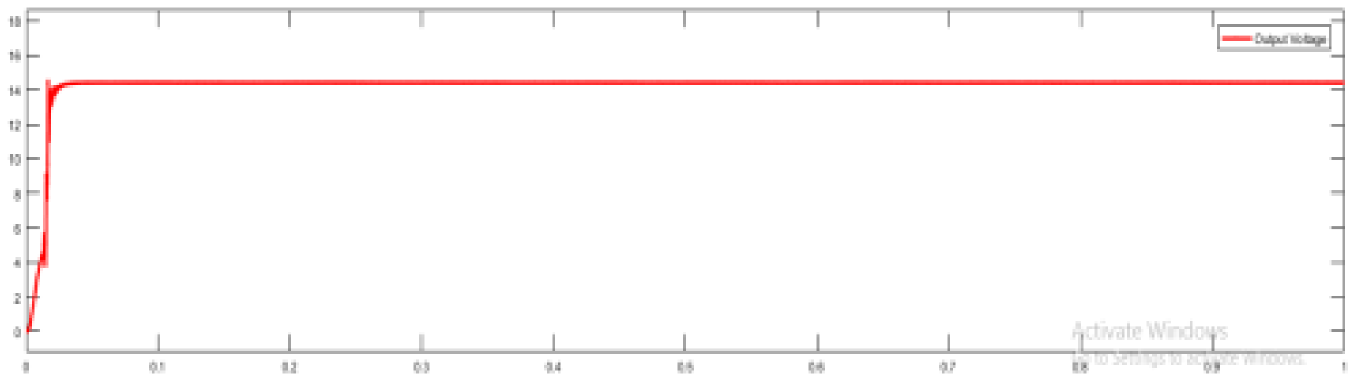

Figure 13. ANFIS simulation result wave in irradiation 800 (W/m²)

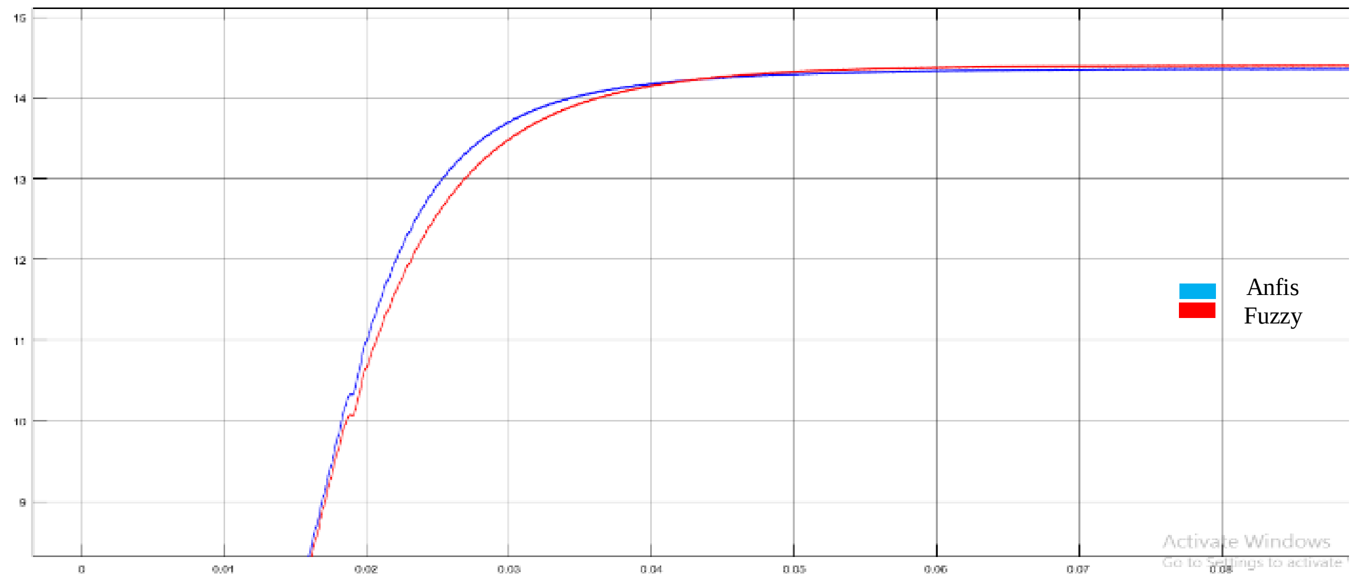

Figure 14. Result wave Comparison ANFIS and FLC in irradiation 800 (W/m²)

IV. Conclusion

From this research it can be concluded that, Fuzzy Logic Controller (FLC) and Adaptive Neuro Fuzzy Inference System (ANFIS) are useful for adjusting the output voltage while the input voltage fluctuates. And from the result can be seen that ANFIS Controller better than FLC. Because the setting point is faster when using ANFIS that it need time 0,04s to get setting point on output voltage.

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