Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control
Journal homepage: http://kinetik.umm.ac.id
ISSN: 2503-2267
Vol. 7, No. 3, August, Pp. 273-288

High accuracy electric water heater using adaptive neuro-fuzzy inference system (ANFIS)

Indhana Sudiharto[1], Farid Dwi Murdianto[*2], Anang Budikarso[3], Putri Taufika[4]
Politeknik Elektronika Negeri Surabaya, Indonesia[1,2,3,4]

Article Info

Keywords:
Adaptive Neuro-Fuzzy Inference System, Electric Water Heater (EWH), Temperature Control

Article history:
Received: May 19, 2022
Accepted: July 21, 2022
Published: August 31, 2022

Cite:
I. Sudiharto, F. Dwi Murdianto, A. Budikarso, and P. Taufika, “High Accuracy Electric Water Heater using Adaptive Neuro-Fuzzy Inference System (ANFIS)”, *KINETIK*, vol. 7, no. 3, Aug. 2022.
https://doi.org/10.22219/kinetik.v7i3.1453

*Corresponding author.
Farid Dwi Murdianto
E-mail address:
farid@pens.ac.id

Abstract

Nowadays, water heater is a common household appliance. Water heater can be divided into three types, based on fuel sources: gas, diesel, and electric. Electric water heater is the most common due to its ease of use. The problems that often occur on electric water heater are over-temperature due to user error in setting up the thermostat and inaccurate readings caused by a conventional system control. These problems will cause a surge in power consumption. Over-temperature and conventional control inaccuracies can be overcome using the Artificial Intelligence (AI) control algorithm in the form of an adaptive neuro-fuzzy inference system (ANFIS). The proposed algorithm acts as a control by maintaining the stability of the temperature to obtain more accurate results. An accurate temperature reading can lower power consumption in electric water heater. This study tries to simulate Electric Water Heater temperature control using the ANFIS algorithm until stable readings can be achieved in all temperature settings. Results from disturbance tests in the form of external condition that causes sudden temperature change show that the system can maintain stability with an average error margin of 0.045% and the rate of accuracy of 99.955%.

1. Introduction

Water is one of the most important resources, especially in its use for personal hygiene. Comfort during bathing can be achieved through regulation of water temperature. One of the mediums that is often used to regulate water temperature is electric water heater (EWH). Temperature settings are dependent on the type of water heater. However, the range of temperature deemed suitable for human body is between 33 degrees Celsius to 37 degrees Celsius[1]. In some states such as Taiwan, USA and Europe which have subtropical climates, the temperature is right in the range of 38.5 degrees Celsius to 40.5 degrees Celsius[2]. Electric Water Heater (EWH) is a household appliance that typically consumes a large portion of electricity, from 7.5% to 40% of total energy consumption in a house[3]. Conventional EWH has a reservoir tank, in which water is stored. The temperature is set to a range suitable for usage and it also stores cold water. Conventional control on EWH is the on-off switch. When the EWH is activated, room temperature water (the lower threshold) in the tank will be heated. When water temperature has reached the upper threshold, then EWH will switch off. The drawback of the reservoir with on-off system is its inability to maintain temperature stability and duration in which desired temperature is achieved[4]. The temperature regulation on EWH is controlled by the thermostat. The thermostat on conventional EWH is located at the bottom of the tank[5]. Most EWHs use analog thermostat, and compared to the digital one, the analog system is less inaccurate because it does not indicate temperature changes during the heating process[6]. In addition to analog EWH, some studies mention the use of a water heater through an automatic faucet using several devices to control the temperature of the water in a bathtub. The resulting system temperature accuracy is 97.6% with a long enough time to reach the temperature for 18 minutes 30 seconds. The controlled temperature is 36 degrees Celsius to 40 degrees Celsius. Excessive temperature can cause problems for the skin condition and health of the user[1].

The temperature system is non-linear and highly complex. Because of its non-linear nature, achieving high accuracy is considered difficult[7]. Therefore, a design or model that can regulate the process well in accordance with the feedback is needed. Generally, system performance depends on the accuracy of the model[8]. The system’s high complexity demands quality control intelligence. Meanwhile, conventional control does not meet the requirements of complex system control**.**

In non-linear systems and high-order, where the system has high uncertainty or variable time characteristics[9]. So, the conventional control with the ON-OFF method which requires limited assumptions cannot be used[10].

The complexity and non-linear properties are directly tied to the type of control being used. In response, artificial intelligence (AI) techniques are introduced as a solution to these problems. The main theory of AI is fuzzy logic and artificial neural network (ANN)[11]. Fuzzy logic has been designed and is successful in controlling non-linear systems. In 1975, Mamdani designed the first fuzzy controller to control a steam engine. In 1985, Takagi and Sugeno introduced a new rule-based system for fuzzy modeling that can be applied to robotics and automotive control systems. On the other hand, there are ANN controllers that are successful in controlling non-linear systems. Until 1993, Jang combined Fuzzy TSK and ANN into a new architecture in the form of ANFIS, and was successfully implemented on many non-linear systems[12]. Fuzzy logic is used to express uncertainty in the system's expert. The problem of fuzzy control is reduced to the acquisition of a collection of if-then rules that are correct and can be obtained from human expertise. The ANFIS method is a combination of the network of artificial conditions and fuzzy logic. Artificial neural networks (ANN) are useful in learning abilities and predicting, while fuzzy logic is useful in reasoning based on existing rules or producing expert systems by itself[10]. To utilize the second function of these controls, ANFIS algorithms (Adaptive Neuro-Fuzzy Inference System) is used to overcome the complexity control, the dynamics and the non-linearity systems[11].

Based on the problems described above, this study will attempt to simulate a system that regulates and control temperatures using ANFIS (Adaptive Neuro-Fuzzy Inference System). ANFIS control is useful for maintaining temperature stability in electric water heater (EWH) system by utilizing its maximum specifications. The system is equipped with modeling based on the relationship between stress and temperature, which forms a polynomial equation. The magnitude of the gain and the time constant will affect how long the system reaches the temperature setpoint. When the temperature has been reached, ANFIS works to maintain a stable output from the system so that the temperature can also be stabilized. The output of the system is obtained from a direct current source which is increased by a converter in the form of a sepic converter. The temperature response will be adjusted to the system output in the form of a duty cycle for each setpoint.

2. Research Method

In this study, the ANFIS method is used to maintain the temperature according to the settings of the point where the settings point that can be selected is between 33°C to 40.5°C. By utilizing the maximum specifications of an Electric Water Heater, the temperature will reach the settings of the point quickly and guarded the stability through the Duty Cycle settings on Sepic Converter.

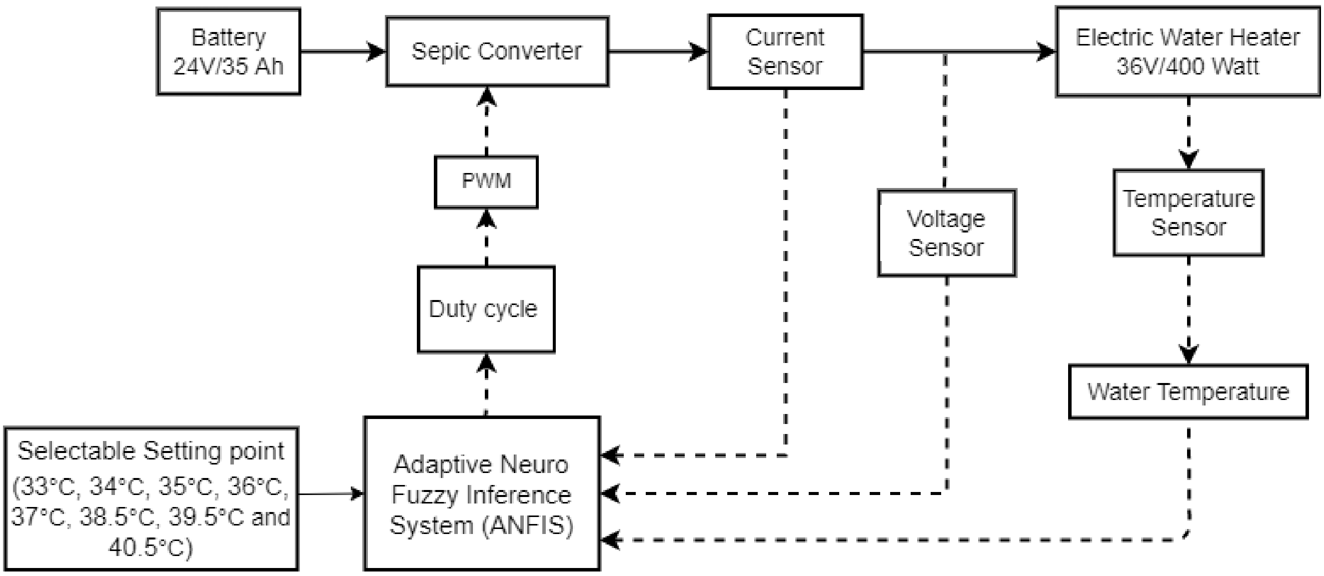


Figure 1. Overall System Temperature Control Electric Water Heater

This study explains the water heating system through the Electric Water Heater with a maximum power of 60 volt 1100 watts. The system is made as a medium for personal hygiene using warm water. The recommended temperature is between 33°C to 40.5°C. With this provision, a water heating system is made with a temperature setpoint 33°C, 34°C, 35°C, 36°C, 37°C, 38.5°C, 39.5°C and 40.5°C with an initial temperature of 29.6°C. Overall system Electric water heater temperature control can be seen in Figure 1.

The supply is used in the form of a lead-acid battery type with a capacity of 24V/35 AH where the full charge battery condition is 28.8 volts. Then the source voltage will be increased using a Sepic Converter up to 60 V to maximize the performance of the Electric Water Heater. Duty Cycle will be arranged until the heater can reach the desired setpoint. When the temperature has been reached, ANFIS as control will automatically stabilize the output of Sepic Converter so that the temperature remains stable.

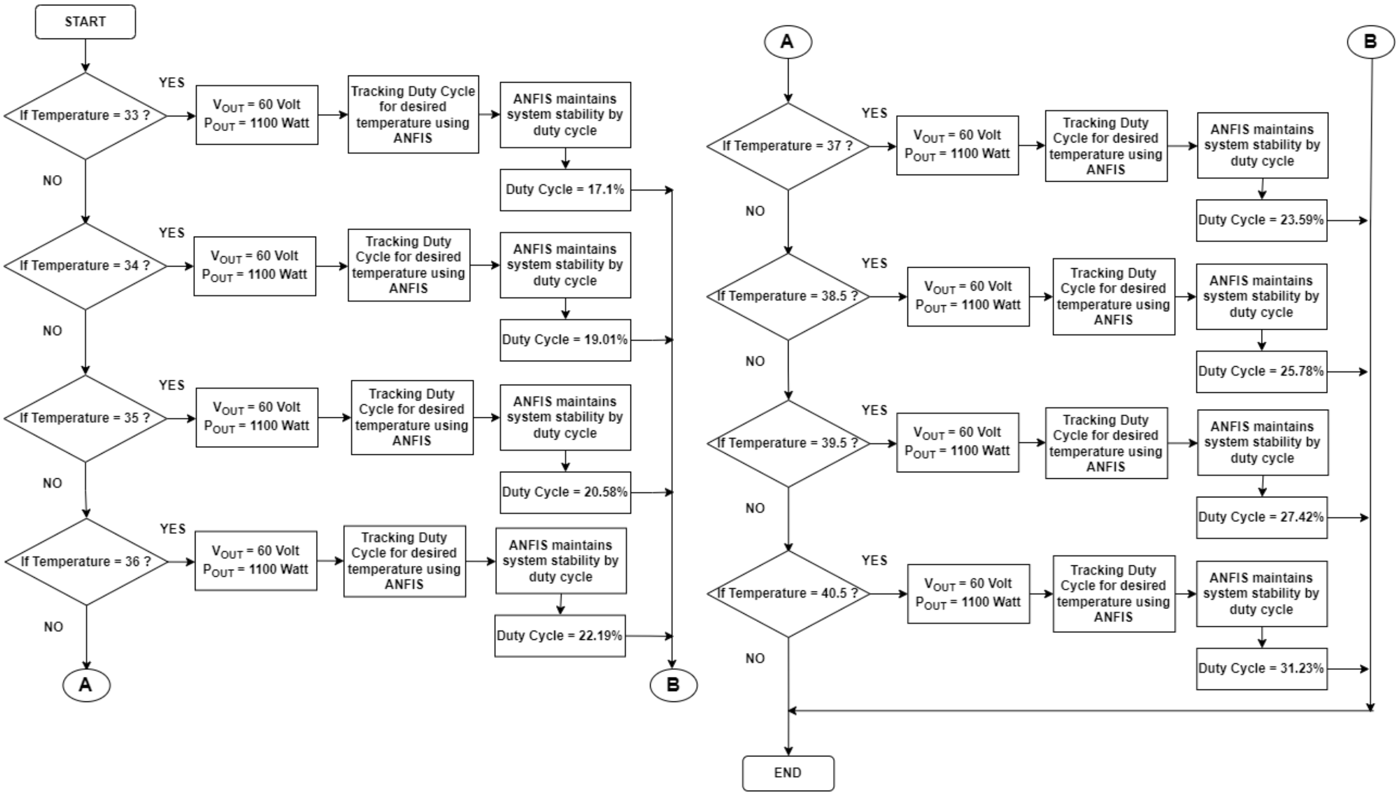


Figure 2. Flowchart System

There is a concept of 4 processes in the electric water heater system, namely the selection of water temperature, heating process, water temperature detection, and maintaining water temperature stability after reaching the point settings. The system is used by 8 temperature point settings, including 33°C, 34°C, 35°C, 36°C, 37°C, 38.5°C, 39.5°C and 40.5°C. The flowchart Temperature System is shown in Figure 2. The initial process is the selection of temperatures according to the desired point settings. Then proceed with the heating process with the maximum capacity of the electric water heater of 60 Volt 1100 watts with an initial temperature of 29.6°C. During the heating process, the temperature will continue to increase, allowing overheating. To prevent overheating, the algorithm is used in the form of an Adaptive Neuro-Fuzzy Inference System (ANFIS). ANFIS will work by detecting water temperature, where the algorithm will keep the temperature stability according to the setpoint through the Duty Cycle settings. Each setting point has a different Duty Cycle value, which is a temperature of 33°C will be stable at Duty Cycle 17.1%, a temperature of 34°C will be stable on Duty Cycle 19.01%, a temperature of 35°C will be stable at Duty Cycle 20.58%, Temperature 36°C will be stable on the Duty Cycle 22.19%, 37°C temperature will be stable at Duty Cycle 23.59%, 38.5°C temperature will be stable at Duty Cycle 25.78%, 39.5°C temperature will be stable at Duty Cycle 27.42%, and 40.5°C temperature will be stable at Duty Cycle 31.23%. That way, the five selected point settings can be maintained stability until the heating process is complete.

2.1 DS18B20 Sensor Response to Electric Water Heater Performance

The DS18B20 sensor is the first temperature sensor to support the "First Line Bus" interface produced by Dallas Semiconductor. The advantages of the sensor are easy configurations, high performance, and miniaturization, which can directly change the temperature into serial data signals[13]. The DS18B20 operating temperature is in the range of -50 ° C to 125 ° C with an accuracy of ±0.1%[14]. In the system, the temperature sensor functions by sensing the amount of temperature produced. Data from the sensing data will form a curve and equation. Through the equation, the relationship will be obtained between the input and output of a system.

To express the relationship, there is a mathematical calculation model called the transfer function. The transfer function is a depiction of a time-invariant system of complex variables. In engineering, the transfer function functions well in terms of control through the mathematical modeling function of the device output for each potential input[15].

We can define the transfer function H(s) with the continuous-time signal input x(t) and Output y(t), where t is a time invarie[16]. Function transfer representation is shown in Figure 3.

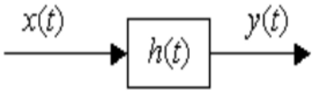


Figure 3. Block Representation of Transfer Function[16]

In the Laplace Integral Domain Time Function f(t) is expressed into the complex function F(s), called the Laplace transformation. The transfer function on the Laplace transformation is expressed in Equation 1 below.

$$H(s) = \frac{Y(s)}{X(s)} \tag{1}$$

The equation output is obtained from the response of the DS18B20 temperature sensor to the performance of the electric water heater. The amount of data output is expressed through the relationship between temperature and voltage. To get this data, EWH is given input in the form of a voltage source with varying numbers. This is done to determine the temperature value of achieving steady conditions at several input voltage steps. As a result, the temperature is not linear during the increase in voltage so that the resulting polynomial equation y = 7E-05x^4 - 0.0064x^3 + 0.1763x^2 - 0.6868x + 32.675. The graph is shown in Figure 4.

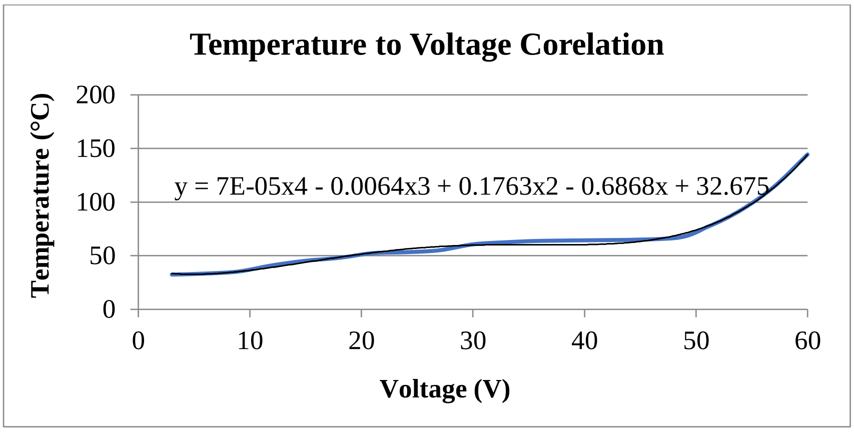


Figure 4. The Temperature Response to the Voltage

The equation that has been obtained will be connected to the transfer function as the response of each set point to the value and time of steady achievement. The transfer function model in a non-linear system requires feedback control, where in this system a step response method is made using the following Equation 2 [10].

$$G(s) = \frac{K}{sTe^{-s\tau} + 1} \tag{2}$$

Where K is the gain, T is the time constant, and τ is the time delay. The following Table 1 shows the gain and settling time at each setting point [10].

Table 1. Gain and Time Set Point Temperature

Temperature (°C)	Gain	Time (s)
33	1.007	66.84
34	0.996	77.4
35	1.0036	83.64
36	0.99	89.04
37	0.988	98.64
38.5	1.0024	100.23
39.5	0.998	103.42
40.5	1.003	105.38

2.2 Sepic Converter Modelling

A Sepic converter or single-tip primary inductance converter is a DC-DC converter that is decreasing voltage. The positive input voltage can be increased and lowered by the converter with the results of constant positive voltage output. Sepic converter in this system serves for both, namely raising and reducing the voltage. The increasing function works when the initial conditions of the system in the heating process to the temperature point settings. While the function decreases work when the temperature settings are maintained stable[17].

Some types of converters can work by raising and lowering the voltage. Examples such as converter conventional buck-boost conventional, flyback converter, cuk converter, and sepic converter[18]. How it works from Sepic Converter similar to the Buck-Boost Converter. The difference is, that the input voltage and output on the SEPIC Converter have the same polarity. Meanwhile, the Buck-Boost Converter between the input voltage and output has a reverse polarity[19]. The advantage of the Sepic Converter is that it requires a smaller cost than the buck-boost converter and reduces the ripple content in the system[20]. Topology Sepic Converter includes components such as Power Switch (MOSFET), two inductors, two capacitors, and a diode[21].

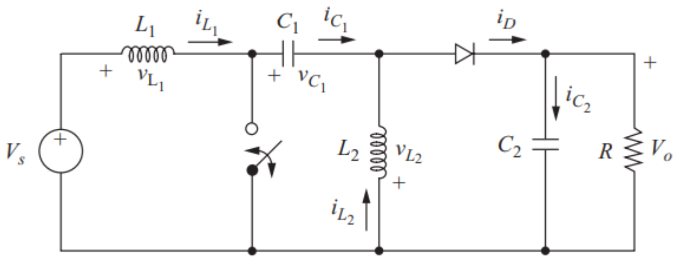


Figure 5. Topology of Sepic Converter[22]

Sepic Converter as DC-DC Converter can be used in two modes, namely switches on and switches off. The switch on the switch occurred when the inductor 1 saves energy, so the number of energy is the same as the source. Then the energy stored by the capacitor 1 will be channeled to the inductor 2. So capacitor 1 experiences discharge and inductor 2 start the charging process. Finally, the voltage contained in the capacitor 2 will be channeled to the load. In this mode diode in reverse conditions.

Whereas in the switch-off mode, the energy stored in inductor 1 will flow to the capacitor 1. Because the diode is in forwarding conditions, the energy stored in inductor 2 will flow to the capacitor 2 through the diode[23]. Sepic converter topology can be seen in Figure 5. Sepic converters will be designed by raising the input voltage from the source by 28.8 volts to the 60 Volt Electric Water Heater capacity. The following is the equation of the Sepic Converter. The formula for the calculation of the Sepic Converter design is presented in Equation 3, Equation 4 dan Equation 5.

$$V_o = \frac{D}{1-D} V_{in} \tag{3}$$

$$L = \frac{V_{in} \times D}{\Delta I_L \times f_s} \tag{4}$$

$$C = \frac{V_o \times D}{R \times \Delta V_o \times f_s} \tag{5}$$

Note :

V_o = Output Voltage
V_{in} = Input Voltage
D = Duty Cycle
L = Induktor
C = Capacitor
ΔV_o = Ripple Voltage
ΔI_L = Ripple Current
f_s = Switching Frequency

Sepic converter parameters can be determined with the provisions of system requirements. The components in it can be calculated by the equation above. Table 2 presents the sepic converter parameter data to be used.

Table 2. Sepic Converter Parameter Design

Parameter	Value
Frequency Switching	100 kHz
Input Voltage	28.8 Volt
Output Voltage	60 Volt
Inductor (L_1 and L_2)	57.88 µH
Capacitor (C_1)	3877.315 µF
Capacitor (C_2)	2326.39 µF
Current Ripple	20%
Voltage Ripple	0.1%

2.3 Design of ANFIS Controller

When in the system there is data that has considerable properties of uncertainty, it is necessary to control with intelligent control in the form of artificial intelligence. One of the artificial intelligence that can be used and is the best choice is Adaptive Neuro-Fuzzy Inference System[24]. Adaptive Neuro-Fuzzy Inference System (ANFIS) is an adaptive network class that is functionally equivalent to the Fuzzy Inference System. ANFIS control model in the form of TSK (Takagi Sugeno) which has the simplicity of calculations[25]. This control utilizes fuzzy capabilities in reasoning and neural networks in learning[26]. The Association of Fuzzy IF-THEN rules is used to expand the architecture of ANFIS[27]. The Equation 6 and Equation 7 is stated as follows.

$$If\ x\ is\ A1\ and\ y\ is\ B1\ then\ f1 = p1\,x + q1\,y + r1 \tag{6}$$

$$If\ x\ is\ A2\ and\ y\ is\ B2\ then\ f2 = p2\,x + q2\,y + r2 \tag{7}$$

Where x and y are crisp input. While AI and BI are linguistic variables[27].

In the Neuro-Fuzzy system, there are 5 layers of process, namely Membership Function, Rules Layer, Normalized Firing Strength, Deffuzification, and Addition[28].

1. Layer 1 (Membership Function)

Each node in this layer is an adaptive node function to node[28]. This layer represents the Fuzzy membership function as a node function with adaptive parameters[29].

$$\mathrm{Oi,1} = \mu A_i\,(x1)\ \mathrm{for}\ i = 1,2 \tag{8}$$

$$\mathrm{Oi,1} = \mu B_{i\ \ 2}\,(y)\ \mathrm{for}\ i = 3,4 \tag{9}$$

x and y are input from the node. Then AI and BI are linguistic labels that show low and high. Whereas for Oi,1 and Oi-2,1 is a certain degree of membership to x and y.

2. Layer 2 (Rules Layer)

This layer serves to set the node using the T-NORM PROD operator. This layer is integrated with layer 1 by multiplying all signals that are in and then the results are sent to the next layer. Each node has a rule. The output of this layer is called weighting[29].

$$\mathrm{Oi,2} = \mathrm{w}i = Ai\,(x) \times Bi\,(y)\ \mathrm{for}\ i = 1{,}2 \tag{10}$$

3. Layer 3 (Normalized firing strength)

The node on this layer is fixed with a normalized degree of membership. So, this node is an output ratio with the previous node[28].

$$\mathrm{Oi,3} = \overline{w_l} = \frac{w_i}{\sum_{i-1}^{16} w_i}\ \mathrm{for}\ i = 1{,}2{,}3{,}4 \tag{11}$$

4. Layer 4 (Deffuzification)

In this layer, each node is an adaptive node to the node function. The node on this layer is adaptive[29].

$$\mathrm{Oi,4} = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i) \tag{12}$$

5. Layer 5 (Addition)
This layer is the sum of all inputs or integration of the previous 4 layers[29].

$$Oi,5 = \sum_{i}^{5} \overline{w_i f}_i = \frac{\sum_i wifi}{\sum_i wi} \tag{13}$$

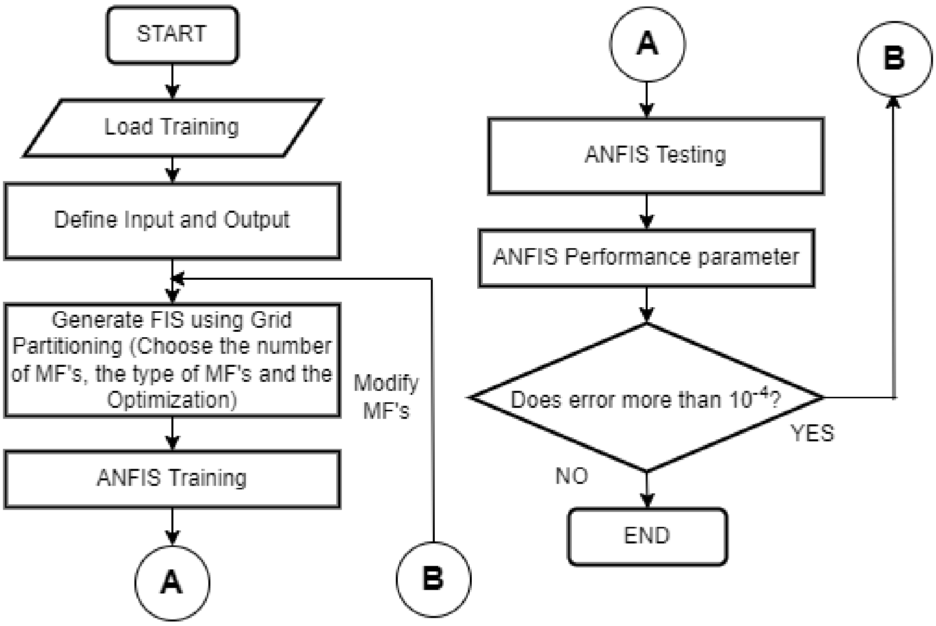


Figure 6. Flowchart ANFIS

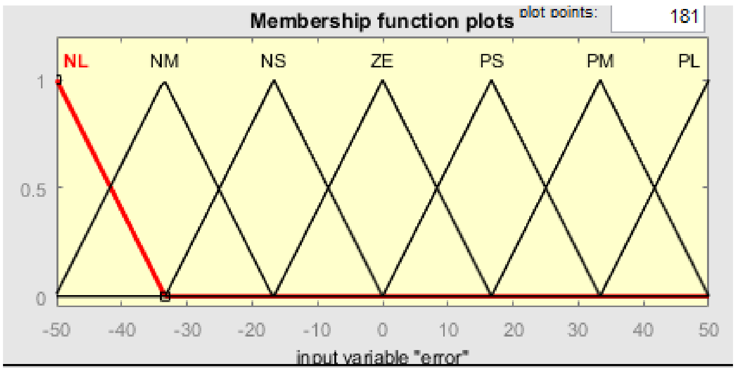


Figure 7. Error Membership Function of ANFIS

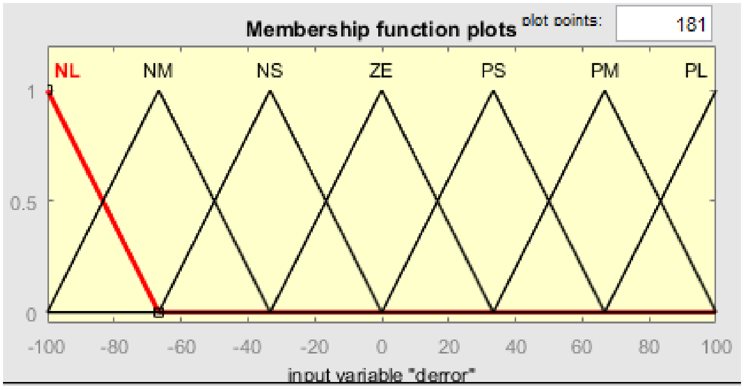


Figure 8. Delta Error Membership Function of ANFIS

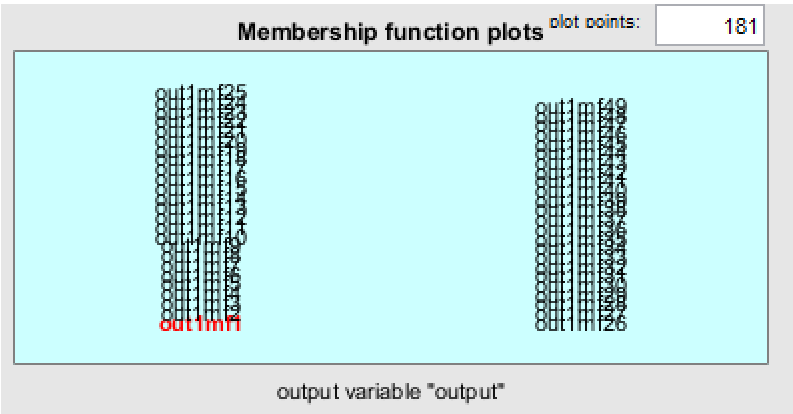


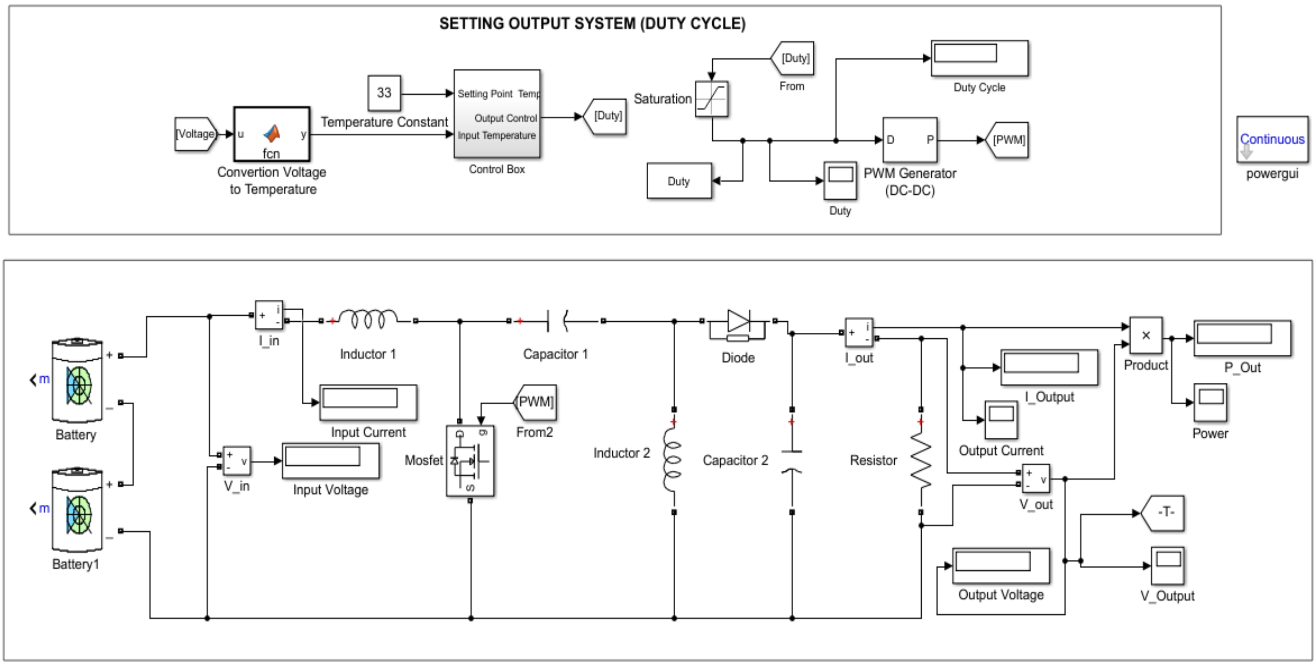
Figure 9. Output Membership Function of ANFIS

ANFIS control consists of load training data to the resulting error value. Data sets are divided into 2, forms training and testing. Generate FIS occurs after the grouping of data. 2 methods can be used in the process of training and testing ANFIS, namely grid partitioning and subtractive clustering. Grid partitioning is considered to have better performance[30]. Before the training process, the type of type and number of membership functions. For training, ANFIS is used Back Propagation and Hybrid (Back Propagation Algorithm with Least Squares). The process can be seen in Figure 6.

In this study, the Triangular (TRIMF) type was used with the number of 7x7 (49 output) membership functions. There are 2 inputs in the form of errors and delta errors with output in the form of duty cycles such as Figure 7 and Figure 8. Each membership function has a particular range that has been set in such a way that the control is formed with 49 outputs as shown in Figure 9.

3. Results and Discussion

The temperature system is simulated using the 2016B MATLAB software by presenting a temperature sensor response to the converter output voltage. The relationship between temperature and voltage produces a polynomial equation. Then the equation forms a transfer function that expresses the temperature in each setpoint. The circuit made includes sources in the form of 24V/35 AH batteries, sepic converters, loads in the form of resistors that have been adjusted to the electrical water heater resistance value, as well as control in the form of ANFIS. A series of simulations of the overall system is presented in Figure 10.



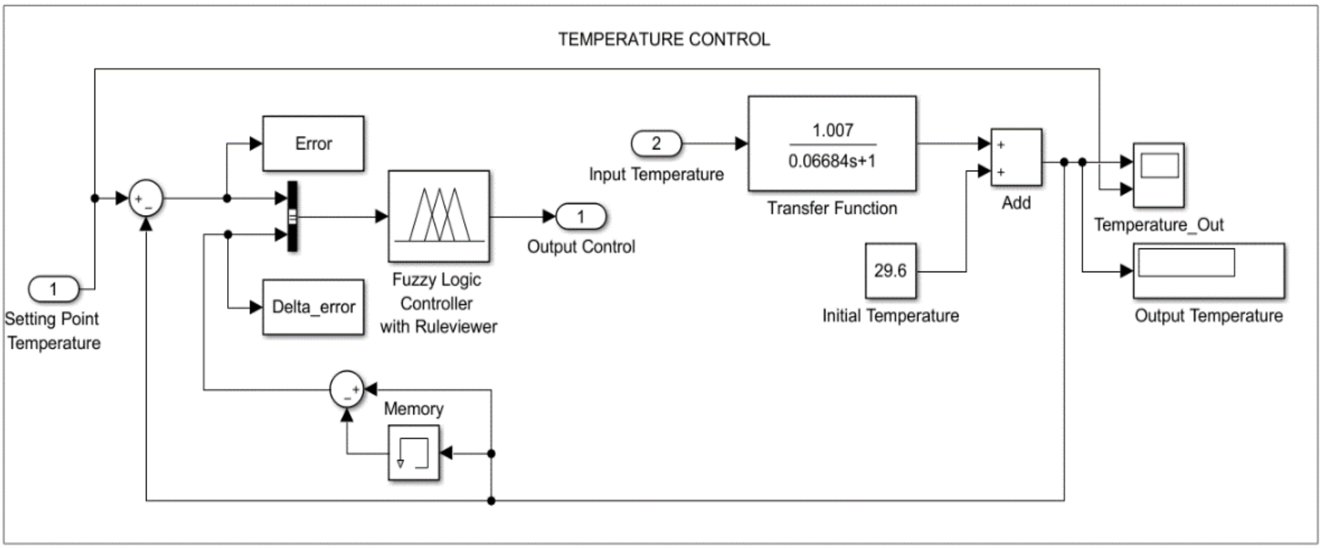
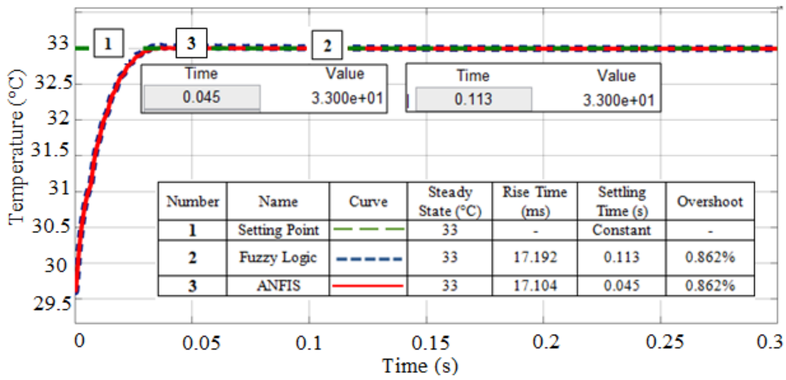


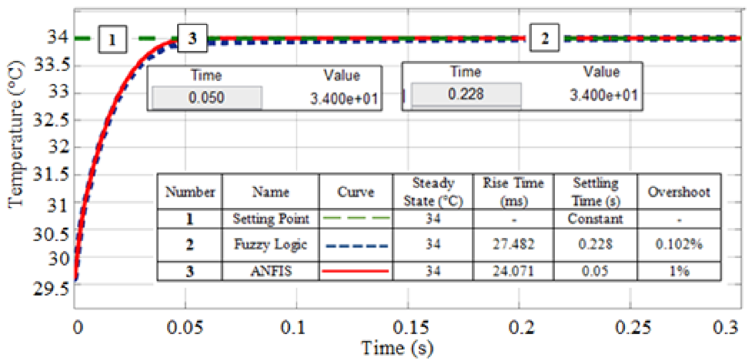
Figure 10. Simulation of Temperature Control System using ANFIS

The output of the SEPIC Converter will be connected with a function block in the form of modeling related to the relationship between temperature and the voltage that forms the polynomial equation $y = 7E\text{-}05x^4 - 0.0064x^3 + 0.1763x^2 - 0.6868x + 32.675$. Through the modeling the function will be made as a form of temperature sensor response to each setpoint with a ratio of **1: 1000** to speed up the simulation process.

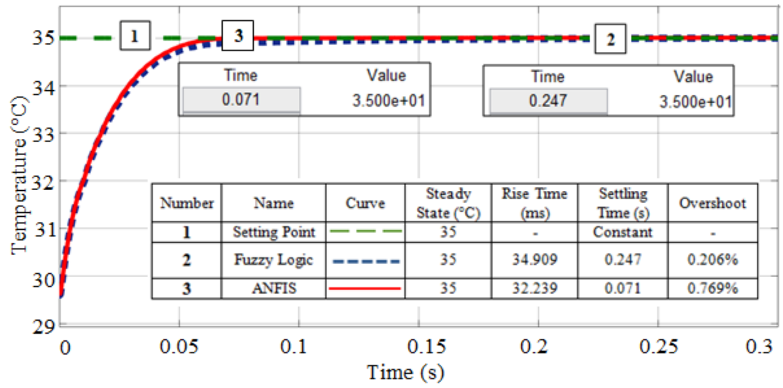
ANFIS controls function to stabilize the output of the SEPIC converter so that the temperature of the setpoint will be achieved quickly with the initial condition in the form of a maximum load capacity. Figure 11 shows the comparison of the simulation results of the fuzzy logic controller and ANFIS controller against the 8 specified temperatures with an initial temperature of 29.6°C.



(a)

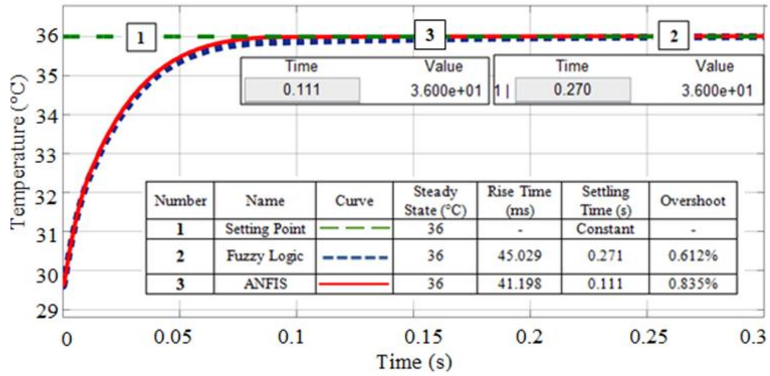


(b)



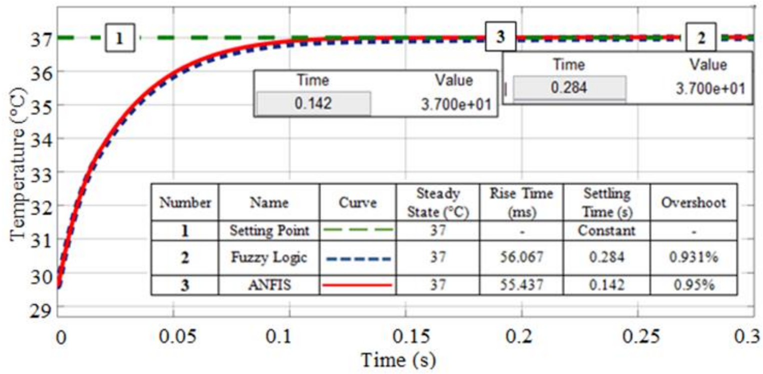
Number	Name	Curve	Steady State (°C)	Rise Time (ms)	Settling Time (s)	Overshoot
1	Setting Point	— — —	35	-	Constant	-
2	Fuzzy Logic	- - - - -	35	34.909	0.247	0.206%
3	ANFIS	———	35	32.239	0.071	0.769%

(c)



Number	Name	Curve	Steady State (°C)	Rise Time (ms)	Settling Time (s)	Overshoot
1	Setting Point	— — —	36	-	Constant	-
2	Fuzzy Logic	- - - - -	36	45.029	0.271	0.612%
3	ANFIS	———	36	41.198	0.111	0.835%

(d)

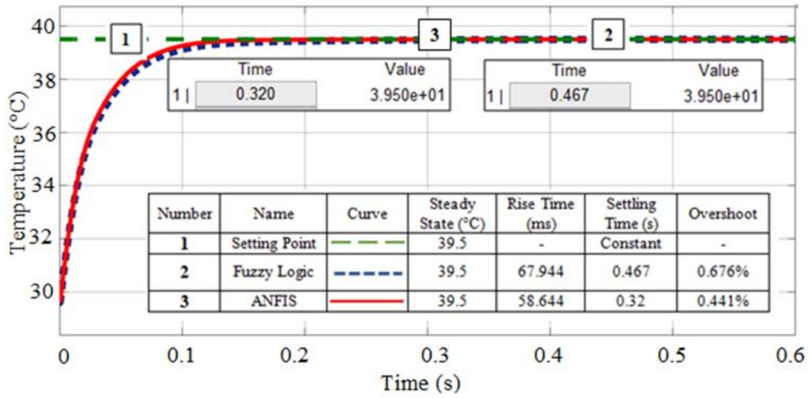


Number	Name	Curve	Steady State (°C)	Rise Time (ms)	Settling Time (s)	Overshoot
1	Setting Point	— — —	37	-	Constant	-
2	Fuzzy Logic	- - - - -	37	56.067	0.284	0.931%
3	ANFIS	———	37	55.437	0.142	0.95%

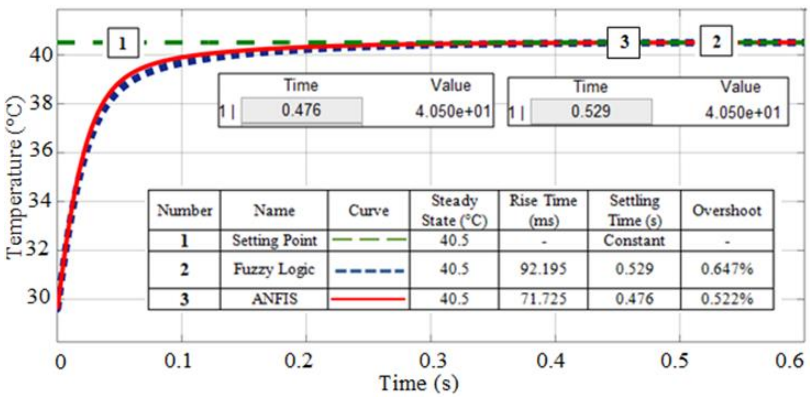
(e)

Number	Name	Curve	Steady State (°C)	Rise Time (ms)	Settling Time (s)	Overshoot
1	Setting Point	— — —	38.5	-	Constant	-
2	Fuzzy Logic	- - - - -	38.5	59.273	0.342	0.309%
3	ANFIS	———	38.5	55.105	0.231	0.433%

(f)



(g)



(h)

Figure 11. Comparison of Temperature Simulation Results with Fuzzy Logic Controller and ANFIS Controller at Set Points (a) Temperature 33°C, (b) Temperature 34°C, (c) Temperature 35°C, (d) Temperature 36°C, (e) Temperature 37°C, (f) Temperature 38.5°C, (g) Temperature 39.5°C and (h) Temperature 40.5°C.

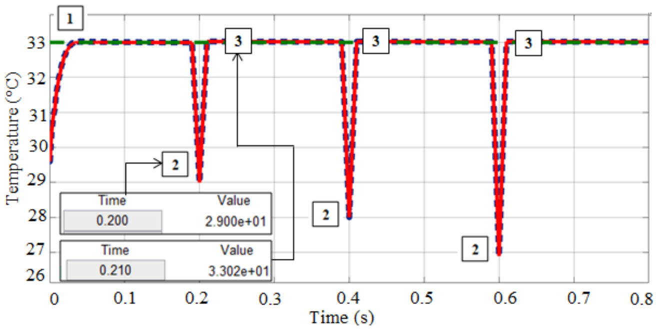
Based on the simulation results with a time ratio of **1:1000**, it can be seen that there is a significant difference in steady time between systems with fuzzy logic control and ANFIS. From Figure 11, two curve lines are formed on each graph, namely the dotted line shows the setting point, the square dotted line shows the fuzzy logic control while the straight line shows the results of ANFIS control over the 8 temperature set points. In fuzzy logic control, achieving the fastest setting point takes up to **1.88 minutes**, while in systems equipped with ANFIS control, achieving a stable temperature setting point only takes **0.75 minutes** at a temperature of 33°C. However, the rise time and the percentage of overshoot of the two controls are not much different, where the speed to reach the set point will affect the overshoot. This happens because the initial condition of the duty cycle is set large enough to accelerate the achievement of the set point. After that, the control will work for temperature stability.

The comparison graph of the performance of the system with fuzzy control and ANFIS shows that the control can reach steady state in a relatively fast time. As shown in Figure 11, the length of time it takes for the control to reach steady state depends on the duration of the desired setpoint temperature. To determine the reliability of fuzzy and ANFIS in control, performance testing was carried out by adding disturbances to natural conditions when the temperature was controlled at steady conditions. To clarify the temperature value used, a cluster is made to determine the minimum and maximum limits for water temperature conditions.

Table 3. Cluster Water Temperature for Bathing

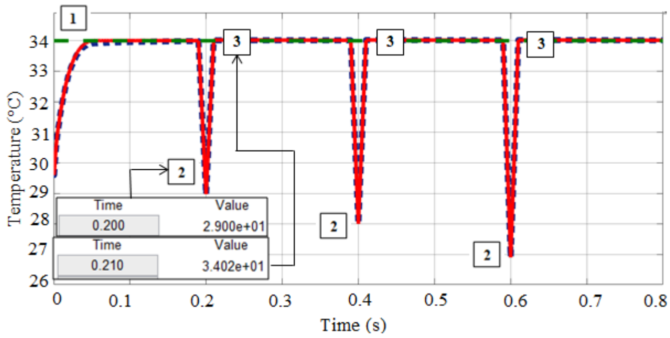
Temperature cluster (°C)	Temperature range (°C)
Normal	±27°C
Warm	33°C – 37°C
Warmer	38.5°C – 40.5°C (for subtropical country)

Table 3 shows the classification of temperature within a certain range. There are 3 clusters of water temperature for bathing, namely normal, warm dan warmer water temperatures (tropical and subtropical country). Based on the water temperature cluster, simulated temperature control was added with disruption to natural conditions at 29°C, 28°C, and 26.8°C which is still classified as a normal water temperature cluster. A comparison of the performance of Fuzzy control and ANFIS control with disturbance is presented in Figure 12. The graph obtained will clarify the speed at which a steady value is achieved.



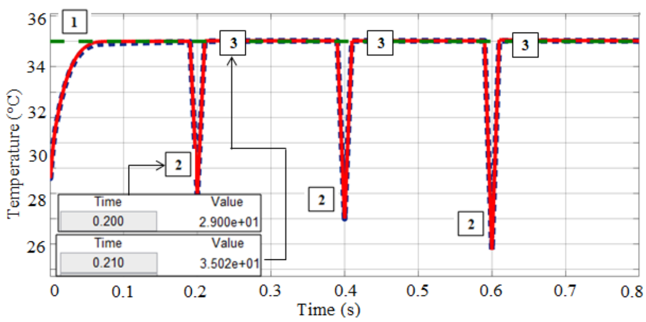
Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	— — —	33	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	- - - - -	33.02	0.21, 0.41, 0.61
3	ANFIS	———	33.02	0.21, 0.41, 0.61

(a)



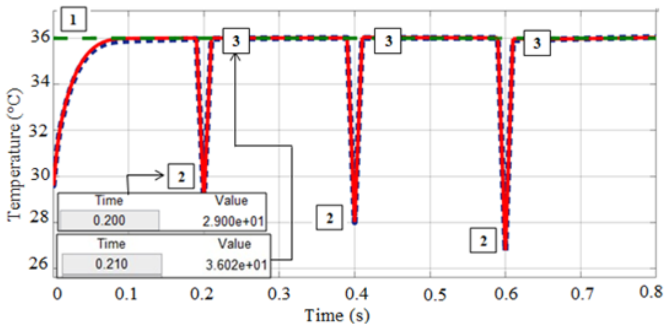
Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	— — —	34	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	- - - - -	34.02	- , 0.41, 0.61
3	ANFIS	———	34.02	0.21, 0.41, 0.61

(b)



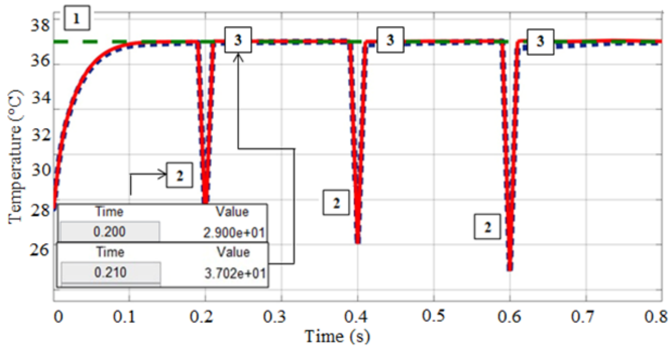
Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	— — —	35	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	------	35.02	- , 0.41, 0.61
3	ANFIS	——	35.02	0.21, 0.41, 0.61

(c)



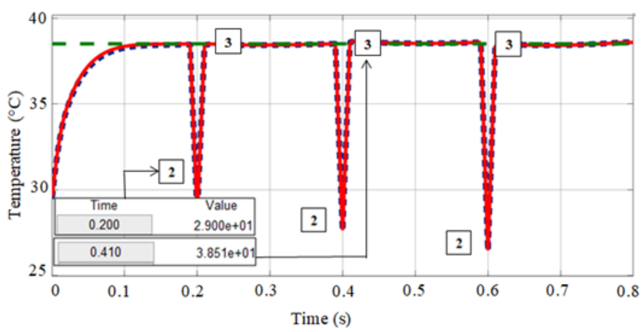
Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	— — —	36	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	------	36.02	- , 0.41, 0.61
3	ANFIS	——	36.02	0.21, 0.41, 0.61

(d)



Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	— — —	37	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	------	37.02	- , 0.41, 0.61
3	ANFIS	——	37.02	0.21, 0.41, 0.61

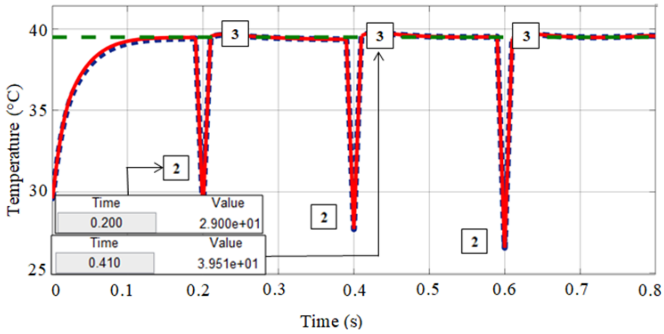
(e)



Cite: I. Sudiharto, F. Dwi Murdianto, A. Budikarso, and P. Taufika, "High Accuracy Electric Water Heater using Adaptive Neuro-Fuzzy Inference System (ANFIS)", KINETIK, vol. 7, no. 3, Aug. 2022. https://doi.org/10.22219/kinetik.v7i3.1453

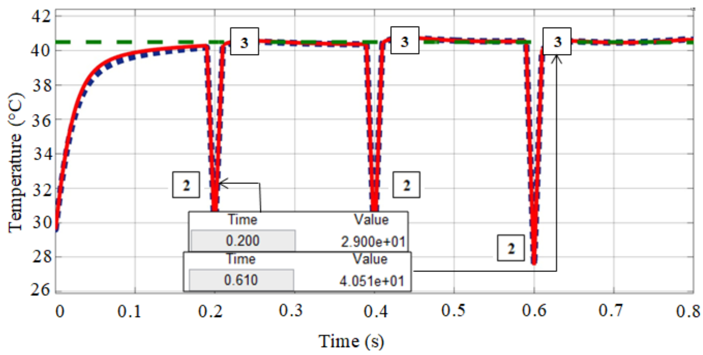
Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	green dashed line	38.5	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	blue dashed line	38.51	- , 0.41, 0.61
3	ANFIS	red solid line	38.51	-, 0.41, 0.61

(f)



Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	green dashed line	39.5	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	blue dashed line	39.51	- , -, 0.61
3	ANFIS	red solid line	39.51	-, 0.41, 0.61

(g)



Number	Name	Curve	Temperature (°C)	Settling Time (s)
1	Setting Point	green dashed line	40.5	Constant
2	Disturbance	-	29, 28, 26.8	0.2, 0.4, 0.6
3	Fuzzy Logic	blue dashed line	40.51	- , -, 0.61
3	ANFIS	red solid line	40.51	-, -, 0.61

(h)

Figure 12. Test the Reliability of Temperature Control Using Fuzzy Logic and ANFIS with Natural Conditions 29°C, 28°C, and 26.8°C on Setting Points (a) Temperature 33°C, (b) Temperature 34°C, (c) Temperature 35°C, (d) Temperature 36°C and (e) Temperature 37°C, (f) Temperature 38.5°C, (g) Temperature 39.5°C, (h) Temperature 40.5°C.

From Figure 12 it can be seen that the reliability test on the electric water heater system using Fuzzy control and ANFIS with a time ratio of **1:1000** still works well, which can maintain temperature stability after being disturbed in the form of natural conditions of 29°C, 28°C, and 26.8°C. Disturbance is set at the same time on all set points. Based on the simulation results, after the disturbance, the steady-state achievement time is **1.67 minutes**. However, in fuzzy control there are still transient conditions when the initial disturbance is given at temperatures of 34°C, 35°C, 36°C, and 37°C with a disturbance time of 0.2 s. Meanwhile, at temperatures of 38.5°C, 39.5°C and 40.5°C, both Fuzzy Logic and ANFIS are stable on average after the third disturbance, which is 0.6 s. The electric water heater system which is controlled using Fuzzy and ANFIS can return the setting point precisely and quickly through the duty cycle setting. The equation to get the error value is shown in Equation 14.

$$Error(\%) = \frac{setpoint - disturbance\ test\ result}{setpoint} \quad (14)$$

1. Temperature = 33°C
   Error(%) = $\frac{33-33.02}{33}$ = 0.06%
2. Temperature = 34°C
   Error(%) = $\frac{34-34.02}{34}$ = 0.059%
3. Temperature = 35°C
   Error(%) = $\frac{35-35.02}{35}$ = 0.057%
4. Temperature = 36°C
   Error(%) = $\frac{36-36.02}{36}$ = 0.055
5. Temperature = 37°C
   Error(%) = $\frac{37-37.02}{37}$ = 0.054%
6. Temperature = 38.5°C
   Error(%) = $\frac{38.5-38.51}{38.5}$ = 0.026%
7. Temperature = 39.5°C
   Error(%) = $\frac{39.5-39.51}{39.5}$ = 0.025%
8. Temperature = 40.5°C
   Error(%) = $\frac{40.5-40.51}{40.5}$ = 0.025%

$$Average\ Error = \frac{0.06 + 0.059 + 0.057 + 0.055 + 0.054 + 0.026 + 0.025 + 0.025}{8} = 0.045\%$$

After getting the error value, it can be calculated the accuracy value shown in Equation 15.

$$\begin{gathered} \text{Accuracy}(\%) = 100\% \ \text{Average Error} \\ \text{Accuracy}(\%) = 100\% \ 0.045\% = 99.955\% \end{gathered} \quad (15)$$

From the above equation, the percentage of ANFIS temperature control accuracy is 99.955%. In another research mentioned 5 temperature setpoints from 36°C to 40°C with an average accuracy of 97.6%[1]. From this it can be seen that the presence of ANFIS control makes the system more reliable by increasing accuracy and minimizing errors that occur.

4. Conclusion

The temperature system uses an algorithm in the form of an Adaptive Neuro-Fuzzy Inference System (ANFIS) that aims to maintain the stability of the temperature so as not to exceed the specified setpoint. The simulation results that have been done indicate that the control can maintain temperature stability with the fastest time of 0.75 minutes at a setpoint of 33°C. The comparison between Fuzzy logic and ANFIS control performance can be seen when the steady-state is reached, where ANFIS is 1.13 minutes faster at 33°C. To see control can work optimally, a disturbance test is carried out by adding temperature disorders from outside suddenly when the temperature is controlled shows steady. From the simulation, it can be seen that ANFIS continues to work optimally by restoring the stability of the temperature after the disturbance occurs. At 8 different settings, the existence of these disturbances results in a control accuracy of 99.955%.

Acknowledgment

Thanks to the Politeknik Elektronika Negeri Surabaya which has been a container of researchers to develop this journal research. Hopefully, this research can make a great contribution to the advancement of technology in Indonesia.

References

[1] M. D. Khairunnas, E. Ariyanto, and S. Prabowo, "Design and Implementation of Smart Bath Water Heater Using Arduino," in *2018 6th International Conference on Information and Communication Technology (ICoICT)*, Bandung, May 2018, pp. 184–188. https://doi.org/10.1109/ICoICT.2018.8528772

[2] C.-L. Cheng and M.-C. Lee, "Research on Hot Water Issues in Residential Buildings in Subtropical Taiwan," *Journal of Asian Architecture and Building Engineering*, vol. 4, no. 1, pp. 259–264, May 2005. https://doi.org/10.3130/jaabe.4.259

[3] M. T. Ahmed, P. Faria, O. Abrishambaf, and Z. Vale, "Electric Water Heater Modelling for Direct Load Control Demand Response," in *2018 IEEE 16th International Conference on Industrial Informatics (INDIN)*, Porto, Jul. 2018, pp. 490–495. https://doi.org/10.1109/INDIN.2018.8472102

[4] B. Lin, S. Li, and Y. Xiao, "Optimal and Learning-Based Demand Response Mechanism for Electric Water Heater System," *Energies*, vol. 10, no. 11, p. 1722, Oct. 2017. https://doi.org/10.3390/en10111722

[5] C. Kizilors and D. Aydin, "Effect of thermostat position and its set-point temperature on the performance of a domestic electric water heater," *International Journal of Low-Carbon Technologies*, vol. 15, no. 3, pp. 373–381, Aug. 2020. https://doi.org/10.1093/ijlct/ctaa007

[6] C. Colon, “Side-by-Side Testing of Water Heating Systems: Results from the 2013–2014 Evaluation,” pp. 43.
[7] T. P. Mote and D. S. D. Lokhande, “Temperature Control System Using ANFIS,” vol. 2, no. 1, p. 6, 2012.
[8] B. Bhushan, A. K. Sharma, and D. Singh, “Fuzzy & ANFIS based temperature control of water bath system,” in *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Delhi, India, Jul. 2016, pp. 1–6. https://doi.org/10.1109/ICPEICES.2016.7853729
[9] R. Babuška and H. Verbruggen, “Neuro-fuzzy methods for nonlinear system identification,” *Annual Reviews in Control*, vol. 27, no. 1, pp. 73–85, Jan. 2003. https://doi.org/10.1016/S1367-5788(03)00009-9
[10] S. Ravi and P. A. Balakrishnan, “Modelling and control of an anfis temperature controller for plastic extrusion process,” in *2010 International Conference on Communication Control and Computing Technologies*, Nagercoil, Tamil Nadu, India, Oct. 2010, pp. 314–320. https://doi.org/10.1109/ICCCCT.2010.5670572
[11] H. Oubehar, A. Selmani, A. Ed-Dahhak, A. Lachhab, M. E. H. Archidi, and B. Bouchikhi, “ANFIS-Based Climate Controller for Computerized Greenhouse System,” *Adv. sci. technol. eng. syst. j.*, vol. 5, no. 1, pp. 8–12, Jan. 2020. http://dx.doi.org/10.25046/aj050102
[12] P. Jagtap, P. Raut, G. N. Pillai, F. Kazi, and N. M. Singh, “Extreme-ANFIS: A novel learning approach for inverse model control of Nonlinear Dynamical Systems,” in *2015 International Conference on Industrial Instrumentation and Control (ICIC)*, Pune, India, May 2015, pp. 718–723. http://dx.doi.org/10.1109/IIC.2015.7150836
[13] Y. Huang, M. Li, and F. Wu, “The Research on Minimum System Construction Management Based on Water Temperature Detector,” *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 612, no. 4, p. 042002, Oct. 2019. https://doi.org/10.1088/1757-899X/612/4/042002
[14] X. Zhao, W. Li, L. Zhou, G.-B. Song, Q. Ba, and J. Ou, “Active Thermometry Based DS18B20 Temperature Sensor Network for Offshore Pipeline Scour Monitoring Using *K* -Means Clustering Algorithm,” *International Journal of Distributed Sensor Networks*, vol. 9, no. 6, p. 852090, Jun. 2013. https://doi.org/10.1155%2F2013%2F852090
[15] A. Atangana and A. Akgül, “Can transfer function and Bode diagram be obtained from Sumudu transform,” *Alexandria Engineering Journal*, vol. 59, no. 4, pp. 1971–1984, Aug. 2020. https://doi.org/10.1016/j.aej.2019.12.028
[16] A. Khandelwal and H. Sharma, “Physical System Analysis Using Matlab,” vol. 04, no. 05, p. 4.
[17] M. Kaouane, A. Boukhelifa, and A. Cheriti, “Design of a synchronous sepic DC-DC converter for a stand-alone photovoltaic system,” in *2015 IEEE 28th Canadian Conference on Electrical and Computer Engineering (CCECE)*, Halifax, NS, Canada, May 2015, pp. 870–874. https://doi.org/10.1109/CCECE.2015.7129389
[18] M. R. Banaei and S. G. Sani, “Analysis and Implementation of a New SEPIC-Based Single-Switch Buck–Boost DC–DC Converter with Continuous Input Current,” *IEEE Trans. Power Electron.*, vol. 33, no. 12, pp. 10317–10325, Dec. 2018. https://doi.org/10.1109/TPEL.2018.2799876
[19] Electrical Engineering Department, NFC IET Multan, Pakistan *et al.*, “Novel Concept of Reducing OVR at the Output of SEPIC Converter using Programmable Capacitors,” *ijeei*, vol. 13, no. 2, pp. 477–494, Jun. 2021. https://doi.org/10.15676/ijeei.2021.13.2.14
[20] V. Gali and P. B. Amrutha, “Fast dynamic response of SEPIC converter based photovoltaic DC motor drive for water pumping system,” in *2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT)*, Nagercoil, India, Mar. 2016, pp. 1–5. https://doi.org/10.1109/ICCPCT.2016.7530298
[21] J. Meher and A. Gosh, “Comparative Study of DC/DC Bidirectional SEPIC Converter with Different Controllers,” in *2018 IEEE 8th Power India International Conference (PIICON)*, Kurukshetra, India, Dec. 2018, pp. 1–6. https://doi.org/10.1109/POWERI.2018.8704363
[22] B. Slimane, A. Othmane, and A. B. Abdelkader, “Unified Power Quality Conditioner Supplied by Fuel Cell System Via SEPIC Converter,” *IJPEDS*, vol. 10, no. 1, p. 178, Mar. 2019. http://doi.org/10.11591/ijpeds.v10.i1.pp178-194
[23] B. Chandan, P. Dwivedi, and S. Bose, “Closed Loop Control of SEPIC DC-DC Converter Using Loop Shaping Control Technique,” in *2019 IEEE 10th Control and System Graduate Research Colloquium (ICSGRC)*, Shah Alam, Malaysia, Aug. 2019, pp. 20–25. https://doi.org/10.1109/ICSGRC.2019.8837093
[24] A. Faruq, A. Marto, N. K. Izzaty, A. T. Kuye, S. F. Mohd Hussein, and S. S. Abdullah, “Flood Disaster and Early Warning: Application of ANFIS for River Water Level Forecasting,” *KINETIK*, pp. 1–10, Feb. 2021. https://doi.org/10.22219/kinetik.v6i1.1156
[25] M. Y. Santoso, A. M. Disrinama, and H. N. Amrullah, “An application of ANFIS for Lung Diseases Early Detection System,” *KINETIK*, pp. 29–36, Feb. 2020. https://doi.org/10.22219/kinetik.v5i1.996
[26] R. Simon and A. Geetha, “Comparison on the Performance of Induction Motor Control Using Fuzzy and ANFIS Controllers,” p. 5.
[27] P. Jagtap and G. N. Pillai, “Comparison of extreme-ANFIS and ANFIS networks for regression problems,” in *2014 IEEE International Advance Computing Conference (IACC)*, Gurgaon, India, Feb. 2014, pp. 1190–1194. https://doi.org/10.1109/IAdCC.2014.6779496
[28] I. Wahyuni, W. F. Mahmudy, and A. Iriany, “Rainfall Prediction Using Hybrid Adaptive Neuro-Fuzzy Inference System (ANFIS) and Genetic Algorithm,” vol. 9, no. 2, p. 7.
[29] N. I. Mufa’ary, I. Sudiharto, and F. D. Murdianto, “Comparison of FLC and ANFIS Methods to Keep Constant Power Based on Zeta Converter,” *Intek*, vol. 8, no. 1, p. 21, Jul. 2021. http://dx.doi.org/10.31963/intek.v8i1.2701
[30] S. N. Qasem, I. Ebtehaj, and H. R. Madavar, “Optimizing ANFIS for sediment transport in open channels using different evolutionary algorithms,” p. 9, 2017. https://dx.doi.org/10.22126/arww.2017.773