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Hybrid System of Dual Axis Photovoltaic Tracking System Using ANFIS-ACO

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Abstract

In this paper, the efficiency of photovoltaic panels is improved by adding two solar tracking systems. The solar tracking system is used to track the sun so that the photovoltaic always faces the sun. This system uses a dual-axis consisting of a horizontal rotation axis and a vertical rotation axis. The motion of the horizontal axis of rotation follows the sun's azimuth angle from north to south. The motion of the vertical axis of rotation following the sun's azimuth angle from east to west is the vertical axis motion. Both types of movement are controlled using PID and Fuzzy controllers which are optimized with an artificial intelligence approach, namely Ant Colony Optimization (ACO). Experiments with PID control approach, Fuzzy control, and ANFIS control were optimized using the ACO method (Hybrid AFIS-ACO method). The results showed that the smallest overshot on the horizontal axis on ANFIS-ACO was 1.346 pu, the smallest undershot on ANFIS-ACO was 0.898, and the fastest settling time on ANFIS-ACO was 0.171 seconds. And on the vertical axis shows the smallest overshot on ANFIS-ACO is 1.287 pu, the smallest undershot on ANFIS-ACO is 0.975, the fastest turnaround time on ANFIS-ACO is 0.105 seconds. This shows that the best model design is in ANFIS-ACO.

Keywords

Ant Colony Optimization, ANFIS, Dual-axis solar tracking system, Hybrid System

INTRODUCTION

The development of science and the use of solar energy is very fast and growing[1]. Solar energy is very promising to be used as a source of energy by converting solar energy into electrical energy. Several optimization methods have been carried out to obtain optimal electrical energy[2][3]. Several artificial intelligence methods have been carried out to obtain optimization of various systems, optimization of micro hydro[4], wind turbines[5][6], water level control[7], vehicle steering control[8][9], and other system optimizations. Artificial intelligence methods that are often used include Fuzzy Logic[10], Firefly Algorithm[11], Ant Colony Optimization (ACO)[12], Bat Algorithm (BA)[2], Imperials Competitive Algorithm (ICA)[13], Particle swarm optimization (PSO)[14], and ANFIS[7]. Using PowerPoint Tracking (MPPT). in a photovoltaic system to track the maximum power point of a PV system using a Fuzzy Logic Controller[15][16]. Another method is also used to obtain electricity, namely by adding a tracking control system to the solar panel or photovoltaic (PV) system[17][18]. PV requires tracking control of the sun's position so that it always precisely follows the sun's position. This solar tracking system is used to track the horizontal axis of rotation and the vertical axis of rotation[19]. The horizontal axis is the axis used to track the sun's elevation angle and the vertical axis is the axis that follows the sun's azimuth angle[20]. Control optimization is needed so that it is positioned exactly as desired.

DUAL AXIS TRACKING

Solar-azimuth-elevation tracking consists of a horizontal rotation axis to track the sun's height from north to south and a vertical axis of rotation to track the angle of the sun's azimuth from east to west as shown in Figure 1. The azimuth angle is the angle formed by the sun clockwise from north to south[18]. The azimuth angle depends on the latitude and time of the year and has an equation like equation 1[21]. The elevation angle is the horizontal angle of the sun. The angle of the sun's height depends on the latitude and time of the year like equation 2.

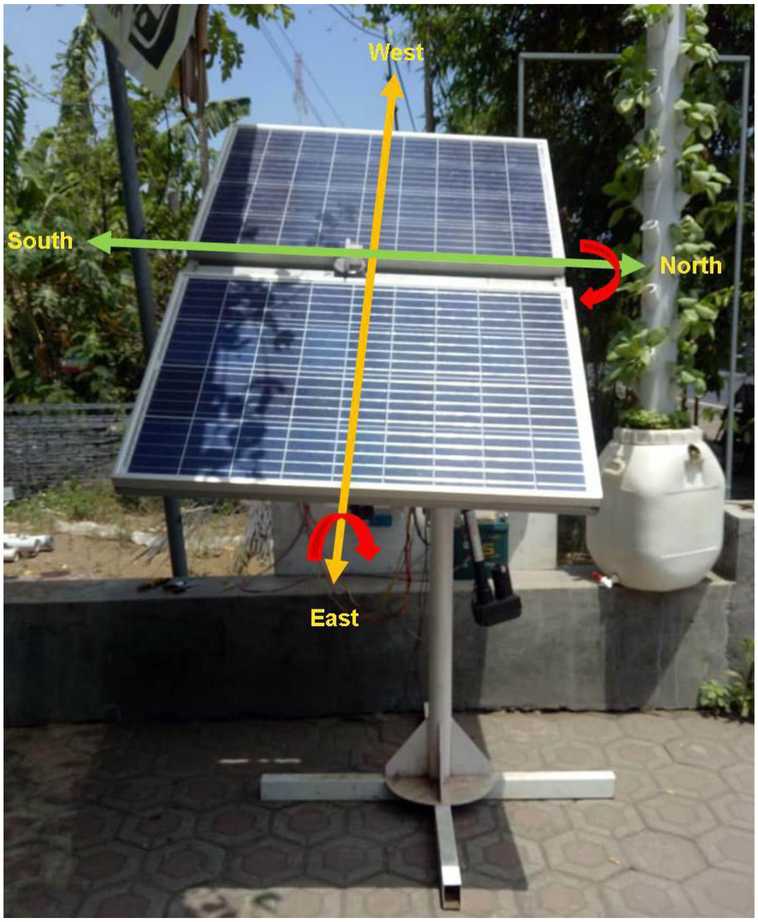

Fig. 1. Dual-Axis Solar Tracking System [9]

$$y = arc\cos \left\{\frac{\sin\delta\cos\varphi - \cos\delta\sin\varphi\ \cos HRA}{\cos a}\right\} \quad (1)$$

$$\alpha = arc\sin(\sin\delta\sin\varphi - \cos\delta\cos\varphi cos(HRA)) \quad (2)$$

Horizontal Axis Solar Tracking System Model

The moment of inertia of the solar cell and the acceleration of the turning angle affect the torque value of photovoltaic loads. Equation 6 is the moment of inertia of the horizontal axis rotary sun. Tracking the horizontal axis rotary sun-like equation 7.

$$J_1 = \frac{1}{2} m_{pv} L^2 (\frac{N_2}{N_1})^2 \quad [kg.m^2] \quad (3)$$

$$J_{T1} = J_{st} + J_1 \quad [kg.m^2] \quad (4)$$

$$J_{T1} = 2.71684x10^{-5} + J_1 \quad [kg.m^2] \quad (5)$$

$$\frac{\theta(s)}{V(s)} i = \frac{K}{s((JT1s+b)(Ls+R)+K^2)} \quad (6)$$

$$\frac{\theta(s)}{V(s)} i = \frac{0.0274}{6.375875x10^{-9}s^3+0.009274s^2+0.0007647308s} \quad (7)$$

Vertical Axis Solar Tracking System Model

Equation 8 represents the moment of inertia of a vertical rotary axis. The moment of inertia of the vertical rotary axis of the solar PV tracker is equation 12 and the transfer function of the vertical rotary axis solar track tracker is equation 15.

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$$J_1 = \frac{1}{2} m_{pv}(L^2 + W^2)(\frac{N_2}{N_1})^2 \quad [kg.m^2] \tag{8}$$
$$J_{T2} = J_{st} + J_2 \quad [kg.m^2] \tag{9}$$
$$J_{T2} = 2.71684x10^{-5} + J_2 \quad [kg.m^2] \tag{10}$$
$$\frac{\theta(s)}{V(s)i} = \frac{K}{s((JT2s+b)(Ls+R)+K^2)} \tag{11}$$
$$\frac{\theta(s)}{V(s)i} = \frac{0.0274}{6.126285x10^{-8}s^3+9.646175x10^{-6}s^2+0.00075076s} \tag{12}$$

PID controller

PID controller is a simple controller that has three controller parameters, namely proportional gain (Kp), integral gain (Ki), and derivative gain (Kd). The PID controller can be tuned using the Ziegler-Nichols method, using the self-tuning method, and using the artificial intelligence method[3][22].

Fuzzy Logic Controller

Fuzzy Logic Controler is based on a logic model that represents the thinking process of the operator in controlling a system. This approach FLC mimics human thinking behavior through conditional linguistic statements. The closed-loop control system on FLC with ER (error) and DE (delta error) as FLC inputs. This rule makes a decision that contains a combination of input and output to be executed. In general, the arrangement of rules set by the FLC in the process control will change according to delta errors and errors. In this study Membership Functions (MF) as a function to express fuzzy membership levels that can be triangular (Triangular Function). Each MF in the input and output consists of five MF in the form of two trapezia and one triangle so that the total base rule required is 25 rules. Every MF has a language term; Super Negative (mf1), Big Negative (mf2), Zero (mf3), Big Positive (mf4), and Super Positive (mf5)[23]. In this paper, the width and position of each MF can be able to be set simultaneously on the input and output parameters of the FLC whose values depend on multipliers Δ. Membership Function can be seen in Figure 2.

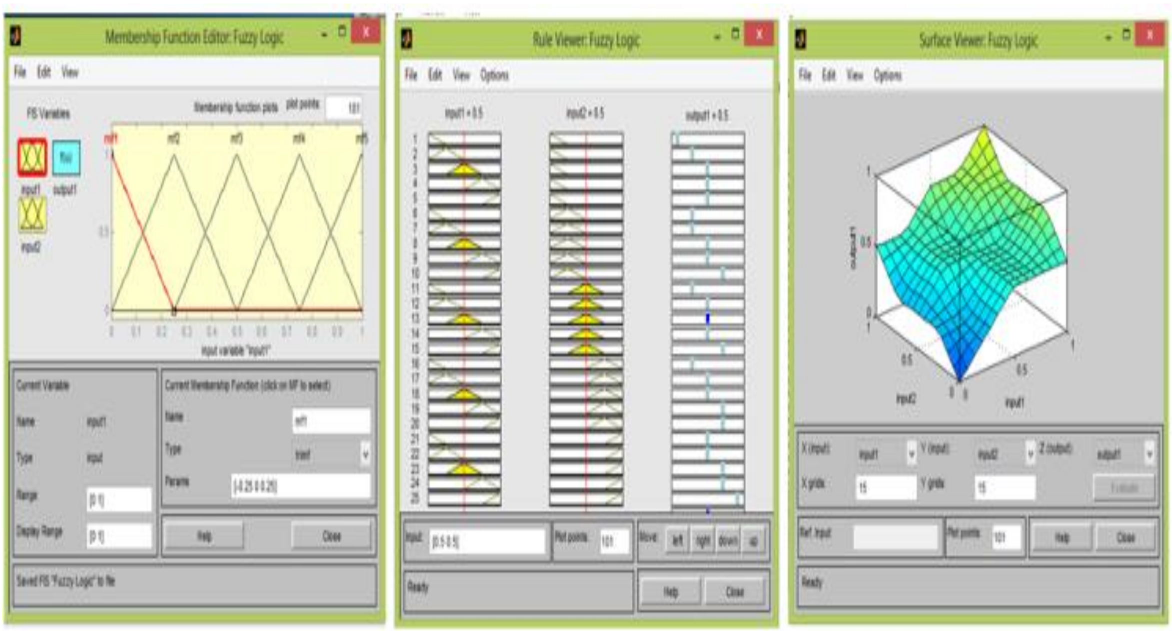

Fig. 2. Membership Function Editor Fuzzy Logic

Ant Colony Optimization (ACO)

ACO algorithm that mimics the behavior of dead ants and sorts the ants' larvae. The ACO algorithm provides relevant partitions of data without the knowledge of the initial cluster center. There are ant agents that randomly move on two-dimensional grids wherein the grid there are randomly scattered objects, and the size of the grid depends on the number of objects. Ant agents that are selected or allowed to move in the grid, will take objects and also drop objects that are affected by the similarity and density of objects[24]. The standard ACO parameters used are shown in Table 1.

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TABLE I
ACO Parameters

ACO Parameters	Value
Node	100
Max_It	50
Alpha(α)	1
Beta(β)	2
rho	0.1
c	100
Kph_aco, Kpv_aco	0-300
Kih_aco, Kiv_aco	0-100
Kdh_aco,Kdv_aco	0-100

RESULTS AND DISCUSSION

The declination of the sun is the angle between the equator and the line drawn from the center of the earth to the center of the sun. The sun's declination results in four seasons in the subtropical regions of both the northern and southern hemispheres.

The transfer function is made into the Matlab Simulink equation as follows can be seen in figure 3. The design uses several methods as comparison, PID auto, Fuzzy Logic, PID-ACO, ANFIS, and ANFIS-ACO can be seen in Figures 3, 4, 5, 6, 7, and 8

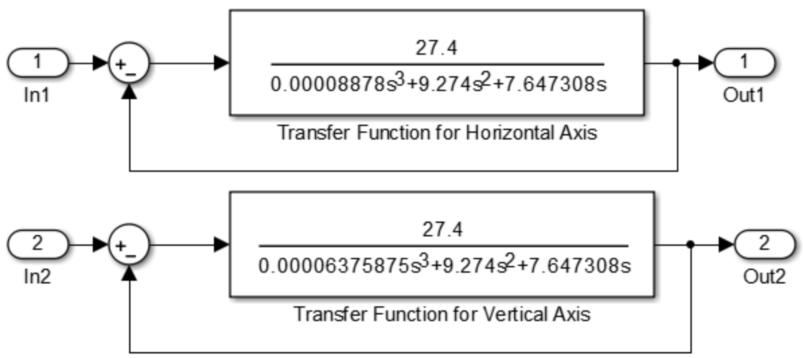

Fig. 3. Design The transfer function for Dual axis simulation

Figure 3 shows the transfer functions for the horizontal and vertical axes

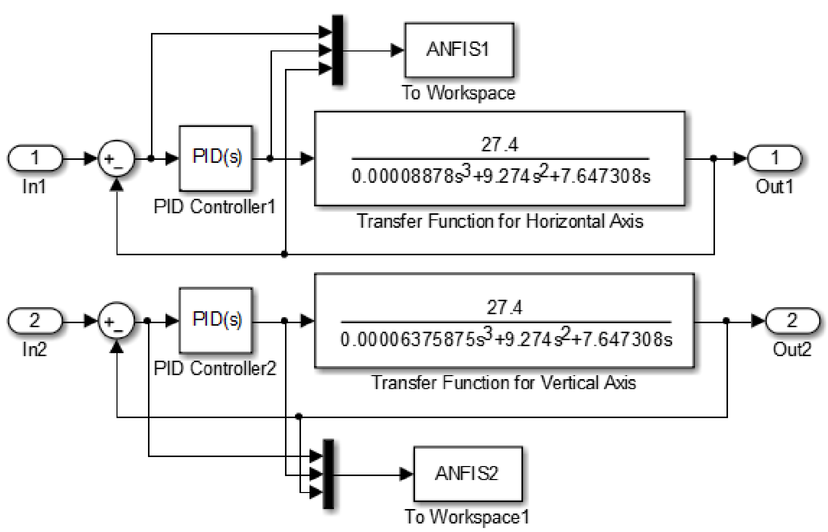

Fig. 4. Design PID Controller for Dual axis simulation

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Figure 4 shows the input and output data from the PID are entered into the workspace to be used as ANFIS input data.

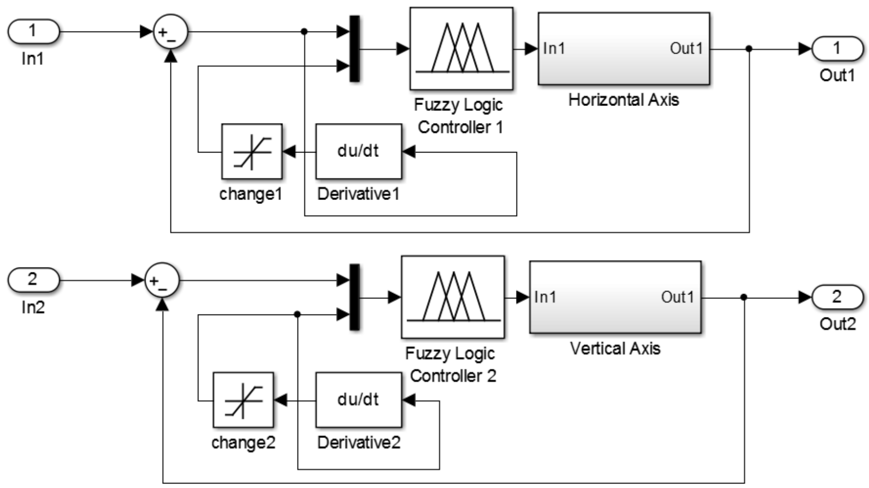

Fig. 5. Design Fuzzy Logic Controller (FLC) for Dual axis simulation

Figure 5 shows the FLC design for dual-axis photovoltaic using 2 fuzzy inputs and 1 fuzzy output.

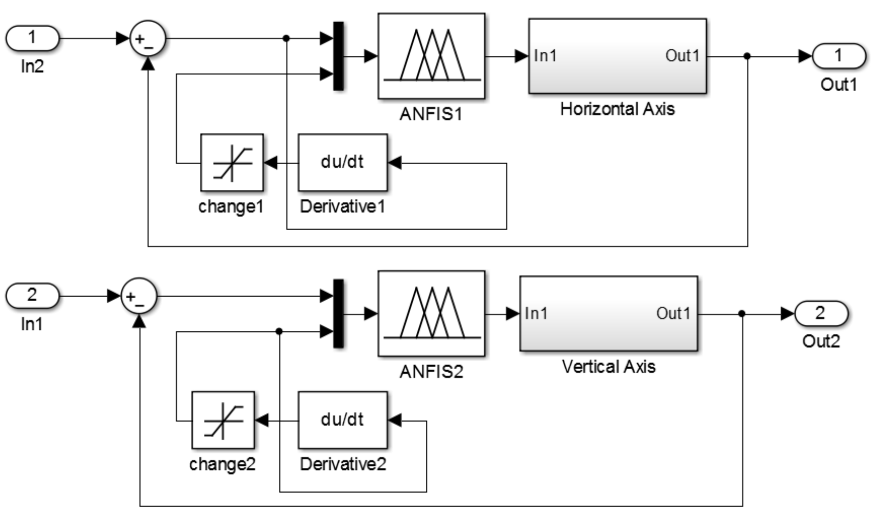

Fig. 6. Design ANFIS for Dual axis simulation

Figure 6 shows the ANFIS design for dual-axis photovoltaic using workspace data from the PID controller.

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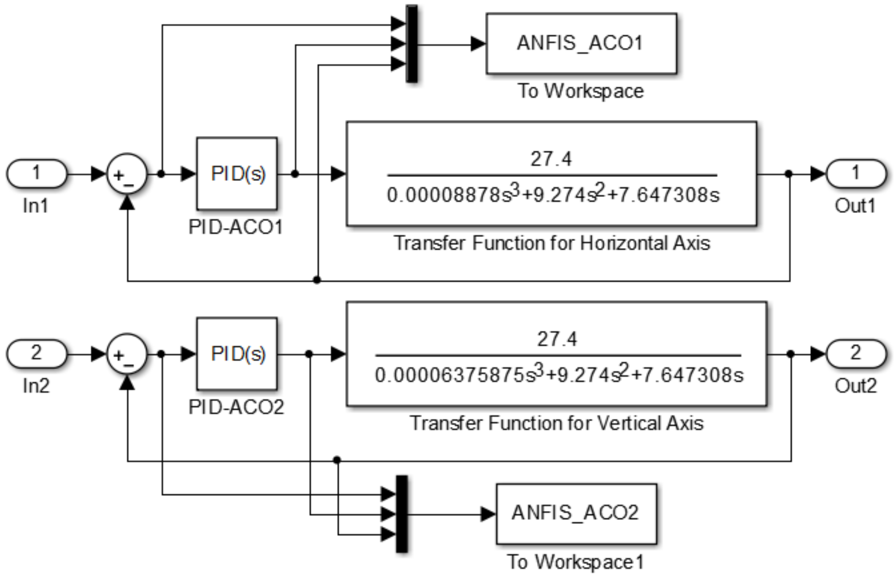

Fig. 7. Design PID-ACO for Dual axis simulation

Figure 7 shows the transfer functions for the horizontal and vertical axes. The input and output data of the PID tuned by Ant Colony Optimization (ACO) are entered into the workspace to be used as ANFIS-ACO input data.

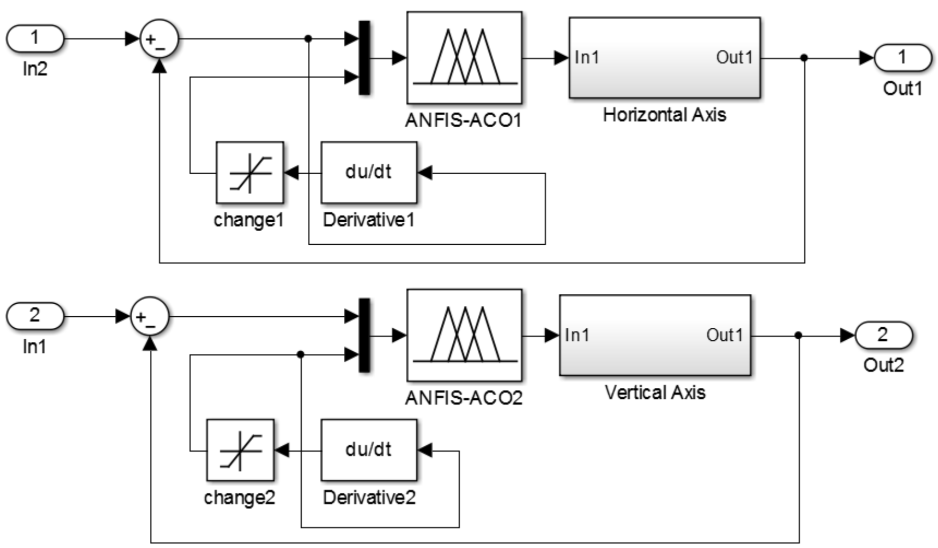

Fig. 8. Design ANFIS-ACO for Dual axis simulation

Figure 8 shows the ANFIS-ACO design for dual-axis photovoltaic using workspace data from the PID tuned by Ant Colony Optimization (ACO) controller.

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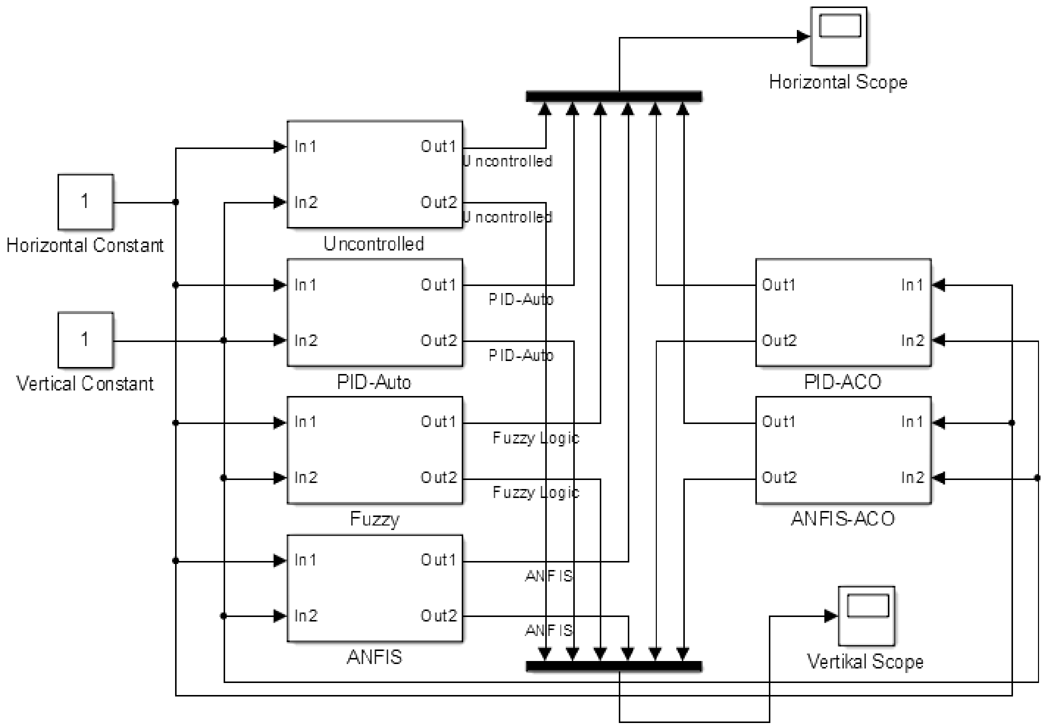

Fig. 9. Design of dual-axis control at Photovoltaic

Figure 9 is a comparison of model control designs; Automatic PID, Fuzzy, ANFIS, PID-ACO, and ANFIS-ACO controllers.

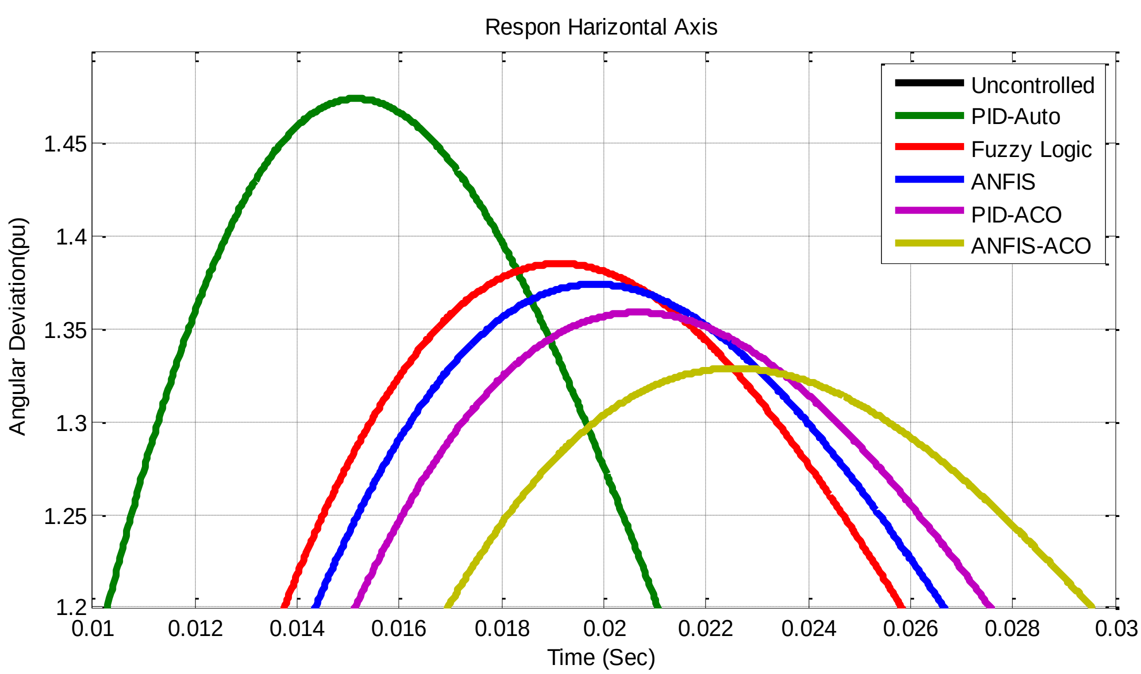

Fig. 10. Overshot Horizontal Axis

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Figure 10 shows a comparison of overshot results on the horizontal axis of the model design; PID-Auto, Fuzzy Logic, ANFIS, PID-ACO, and ANFIS-ACO. It is shown that the most suitable result for reference (1) is the ANFIS-ACO model.

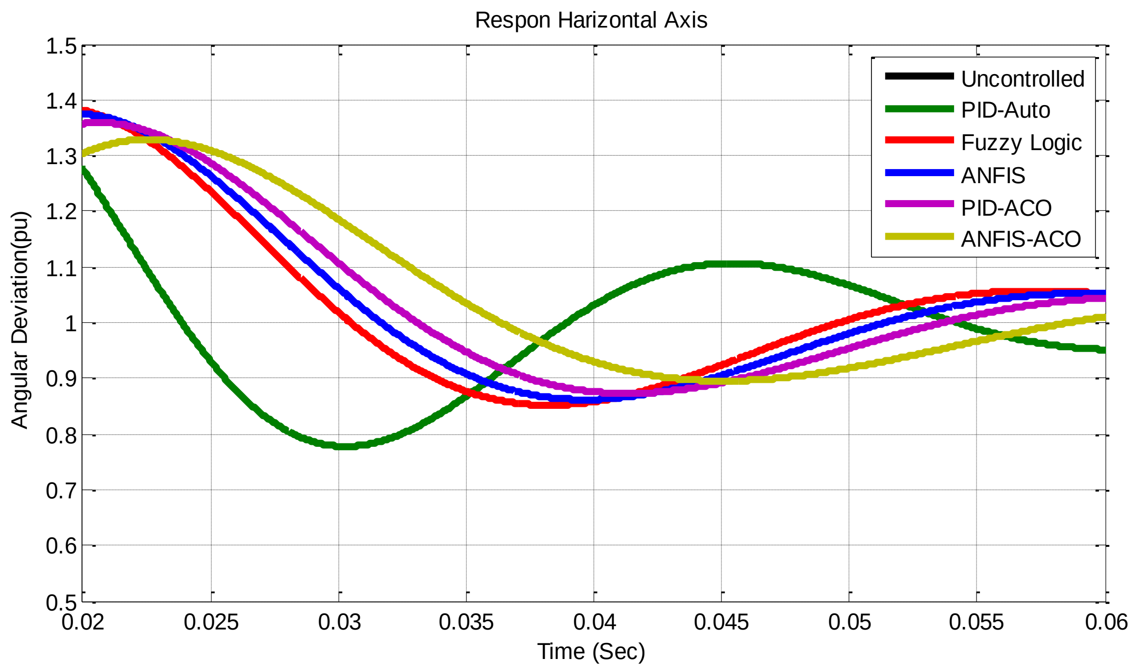

Fig. 11. Undershot Horizontal Axis

Figure 11 shows a comparison of undershot results on the horizontal axis of the model design; PID-Auto, Fuzzy Logic, ANFIS, PID-ACO, and ANFIS-ACO. It is shown that the most suitable result for reference (1) is the ANFIS-ACO model.

TABLE 2
Horisontal Axis Results

	Unc	PID-Auto	Fuzzy	PID-ACO	ANFIS	ANFIS-ACO
Kph	-	187.500	-	94.347	-	-
Kih	-	31.100	-	2.118	-	-
Kdh	-	98.000	-	73.231	-	-
Overshoot (pu)	6.100	1.764	1.384	1.352	1.374	1.346
Undershoot (pu)	0.300	0.783	0.853	0.883	0.856	0.898
Settling time (s)	6.890	0.543	0.432	0.354	0.241	0.171

From table 2 shows that; the largest overshot on uncontrolled and the smallest overshot on ANFIS-ACO was 1,346 pu. The biggest undershot on uncontrolled and the smallest undershot on ANFIS-ACO was 0.898 longest settling time on uncontrolled and fastest on ANFIS-ACO. This shows that the best model design is in ANFIS-ACO was 0.171s.

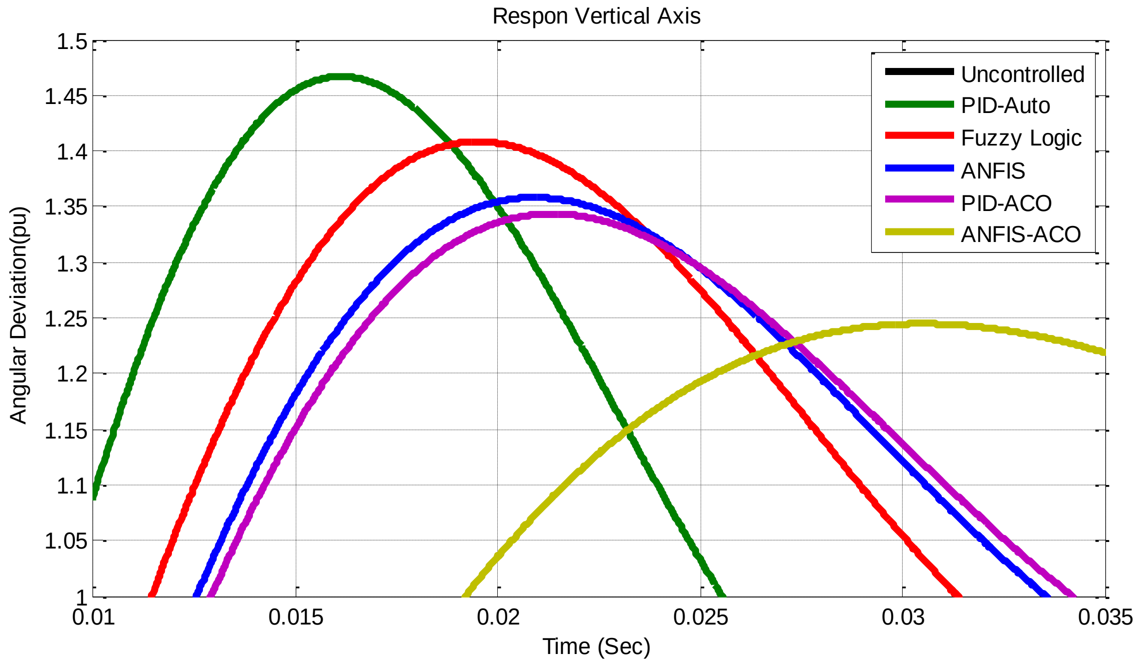

Fig. 12. Overshot Vertical Axis

Figure 12 shows a comparison of overshot results on the vertical axis of the model design; PID-Auto, Fuzzy Logic, ANFIS, PID-ACO, and ANFIS-ACO. It is shown that the most suitable result for reference (1) is the ANFIS-ACO model.

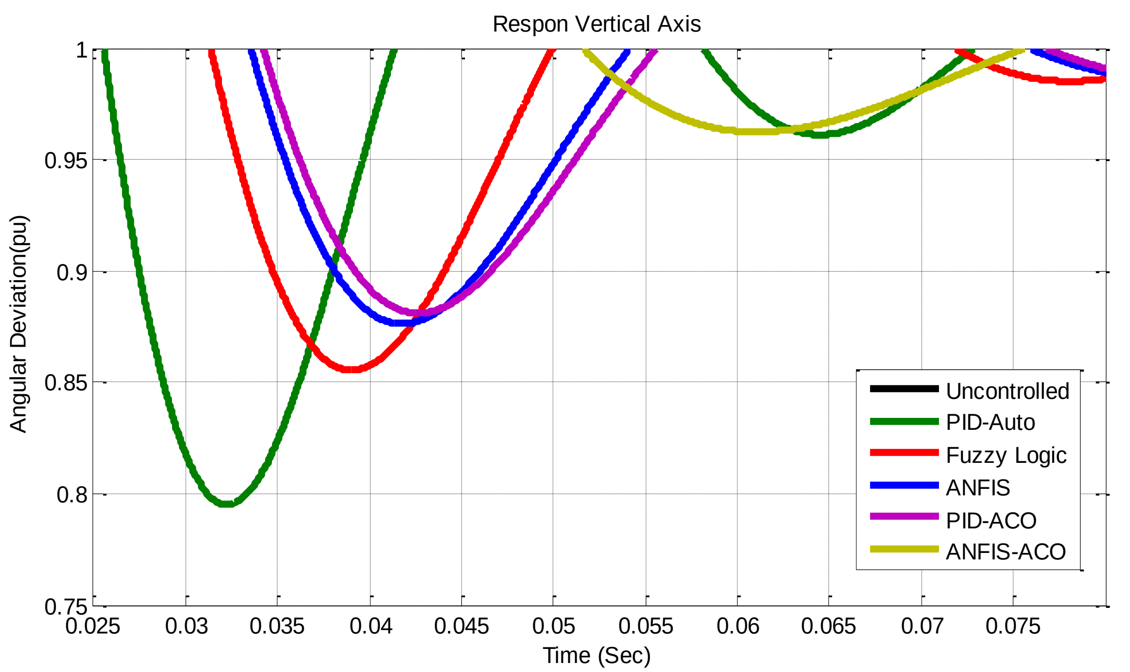

Fig. 13. Undershot Vertical Axis

Figure 13 shows a comparison of undershot results on the vertical axis of the model design; PID-Auto, Fuzzy Logic, ANFIS, PID-ACO, and ANFIS-ACO. It is shown that the most suitable result for reference (1) is the ANFIS-ACO model.

TABLE 3
Vertical Axis Results

	Unc	PID-Auto	Fuzzy	PID-ACO	ANFIS	ANFIS-ACO
Kpv	-	287.2	-	134.053	-	-
Kiv	-	21.40	-	0.060	-	-
Kdv	-	132.5	-	43.385	-	-
Overshot	7.342	1.482	1.432	1.342	1.359	1.287
Undershot	0.214	0.786	0.852	0.863	0.753	0.975
Settling time (s)	5.844	0.522	0.326	0.123	0.233	0.105

From table 3 shows that; the largest overshot on uncontrolled and the smallest overshot on ANFIS-ACO was 1,287 pu. The biggest undershot on uncontrolled and the smallest undershot on ANFIS-ACO was 0.975. longest settling time on uncontrolled and fastest on ANFIS-ACO was 0.105 s. This shows that the best model design is in ANFIS-ACO was 0.105s.

CONCLUSION

The results showed that the smallest overshot on the horizontal axis on ANFIS-ACO was 1.346 pu, the smallest undershot on ANFIS-ACO was 0.898, and the fastest settling time time on ANFIS-ACO was 0.171 seconds. And on the vertical axis shows the smallest overshot on ANFIS-ACO is 1,287 pu, the smallest undershot on ANFIS-ACO is 0,975. the fastest settling time on ANFIS-ACO is 0.105 seconds. This shows that the best model design is in ANFIS-ACO.

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