Optimization of Water Level Control Systems Using ANFIS and Fuzzy-PID Model

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***Abstract*— Water flow measurements have been needed by controllers in industrial processes. The quantity of water must be determined to control the volume of water used in the storage tank. Water flow performance control models based on tanks are required using a Proportional-Integral-Derivative (PID) control system. This system uses a flow sensor to detect the speed of an actuator. Actuators stabilize the output water speed per minute at a certain point. Manually determining the value of a PID constant will be very difficult and not optimal. Then we need an automatic and accurate control method. This study focuses on four comparisons of designed methods related to water level without control, standard PID method, Fuzzy Logic method, Fuzzy-PID method, and Adaptive Neuro-Fuzzy Inference System (ANFIS) method. The simulation results found that the four control models have different performance. The PID-ANFIS model obtained the smallest overshot value in the PID-ANFIS model of 0.5135 pu, the smallest undershot in PID-ANFIS was 0.5291 pu. Current Output Output obtains the smallest overshot value in the PID-ANFIS model of 0.0023 pu, the smallest undershot in the PID-ANFIS model is 0.0014 pu.**

Keywords—ANFIS, Fuzzy Logic, PID, Water Level

I. INTRODUCTION

In general, a physical mechanism of the water level system (WLS) was analyzed while the estimated linear model was also constructed to represent the dynamic property of the WLS around the equilibrium point[1]. Besides, the identification method recognizes the dynamic character of the WLS using measured input and output data. Technically, the water tank level instrument was developed using a nonlinear time process control system, which can be modeled globally or partially as a water system[2]. Moreover, different models lead to different control strategies which were very important for the overall control system design[3].

water level system is widely used in high-pressure heating in steam power plants. water level system is used to control the heat circulation system of the boiler water supply[5-8]. The monitoring of the water level systems must be done to ensure the stability of the high-pressure heating system[9]. Several water level system controls that are implemented are the stable predictive tracking controller model, Fuzzy Logic Controller, fuzzy clustering, and subspace identification[10]. However, the water level system design is still less than optimal and stable.

The electric ball valve was controlled in the tank so that the flow of water that comes out of the tank matches what was needed. Control methods that have been frequently used in research are using PID, Fuzzy, Fuzzy-PID, ANFIS, and a combination of methods with artificial intelligence. This method has been used in solving control system problems. Among them ware frequency control on micro-hydro[10][11], and dual-axis photovoltaic tracking control[12].

II. PROBLEM STATEMENT

Fluid flow measurement control systems were needed by industry to maintain all optimization processes. In detail, this process covers all sequencing production systems. This effort was obtained in the performance system to regulate water flow based on tank volume with PID or Fuzzy control. The PID Control Method requires a constant Kp, Ki, and Kd. The Fuzzy control method requires Fuzzy Logic in the membership function. Besides that method, there was also a combined Fuzzy-PID and/or ANFIS method which was a combination of Fuzzy with a neural network, where training data was taken from PID training data. In principle, these methods ware used to stabilize the output water speed per minute at the setpoint based on various controlled parameters.

A. Flow(Q)

The flow rate was the sum of the volume of fluid flow over time was determined by using the equation (1);

$$Q = \frac{V}{A} \qquad (1)$$

Besides, it was presented at certain time intervals during flow in the system path and was often stated as the following discharge statement (2);

$$Q = \frac{V}{t} \qquad (2)$$

Where Q was a debit (m^3/s), A was a cross-sectional area (m^2), V was a fluid flow rate (m/s), and t was time interval (s).

B. Continuity equation

Water flows in a water pipe was considered to have the same discharge at any point even the size has differed in the type and route. On the flowing fluid, it can be seen in two positions covered for the inlet and outlet during a volume passed the tunnel. By considering these holes, it can be also reviewed as 2 places from the first point as the coming water and the second point as the releasing water which was

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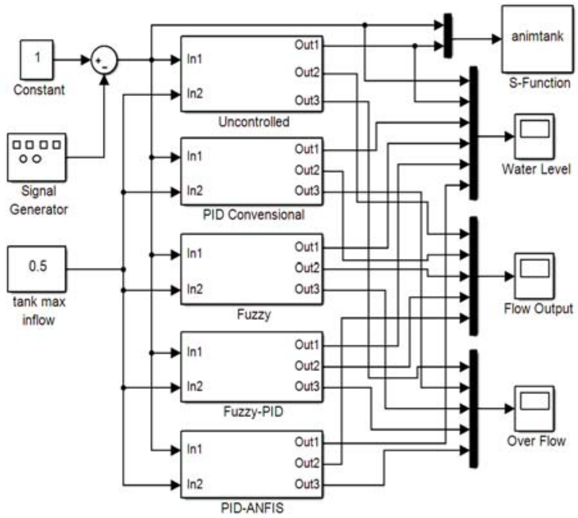


Fig. 1. Surge tank system

run in the same debit. Regarding the flow-rate, the water condition was presented in (3).

$$A_1.V_1 = A_2.V_2 \tag{3}$$

C. Bernoulli Method.

Based on the characteristics of water during flowing in a tube or pipe, water has specific performance covered by the Bernoulli method. This method was presented in determining the energy balance in a water flow system developed as a law based on energy conservation laws experienced by fluid flows. This formula states that the amount of pressure, potential energy, and kinetic energy per unit volume has the same value. Equation 7 is an equation for modeling the water tank subsystem

$$\mathrm{P}_1 + \mathrm{p.g.h}_1 = \mathrm{P}_2 + \frac{1}{2}\mathrm{PV}^2 + \mathrm{p.g.h}_2 \tag{4}$$

$$\mathrm{g}(\mathrm{h}_1 - \mathrm{h}_2) = \frac{1}{2}\mathrm{V}^2 \tag{5}$$

$$\mathrm{V} = \sqrt{2\mathrm{g}(\mathrm{h}_1 - \mathrm{h}_2)} \tag{6}$$

$$\mathrm{V} = \sqrt{2\mathrm{gh}} \tag{7}$$

Where P is the water pressure (Pa), V is the speed of the water (m/s), g was an acceleration of gravity, and the h was the height level of water.

III. Research Method

A. Design of Water Tank System

The water tank system consists of two block subsystems, namely a valve system and a water tank. Both systems have their functions as joined interaction during an existing fluid flow as running as on the processes to complete all interactions of the sequencing parts. Technically, the input system was conditioned by the constant value of water discharge, signal generator, and tank maximum inflow. In general, the flowing of water was supplied using a pump from a storage tank and the water flow rate was adjusted using an actuator as given in Figure 1. It shows the schematic of the surge tank system with two systems of the ins outflow tunnels[13].

Simulink Block uncontrolled diagram can be shown in Figure 2;

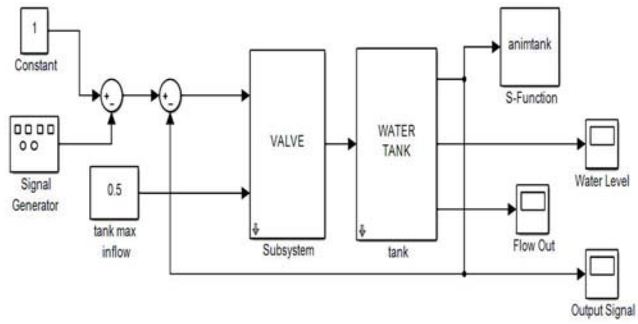


Fig. 2. Simulink Block diagram uncontrolled

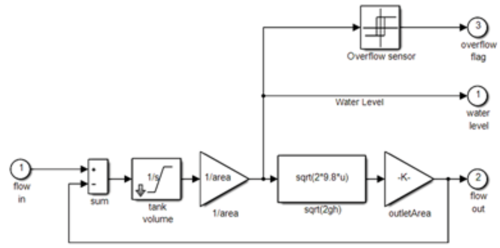


Fig. 3. The Water Tank Subsystem

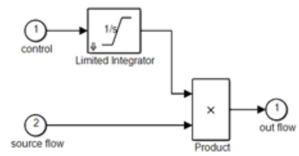


Fig. 4. The Valve Subsystem

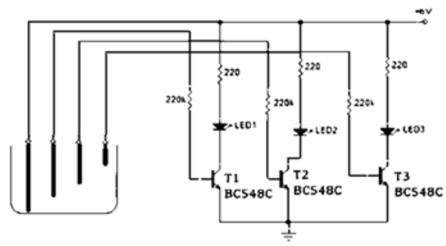


Fig. 5. Indicator lights for Water Level

Regarding the water tank system, Figure 3 shows the Simulink block diagram for the water tank subsystem and Figure 4 shows the valve subsystem. These systems are subjected to control inlet and outlet of the water during flowing in the tunnel or pipe system. the models are developed based on its criteria to reach and perform its characteristic during the water running. Electronic circuit Water level indicator lights can be shown in Figure 5.Conventional PID

PID controller was a combined control system of proportional, integral, and derivative control by considering all the performance of each output. In this method, the adjustment was done in a closed-loop where the reference input is used as a step function designed in the system. This method sets the parameters Kp, Ki, and Kd. So that it was obtained after the system output was reached in the state of steady-state. The Block diagram PID Controller can be shown in Figure 6;

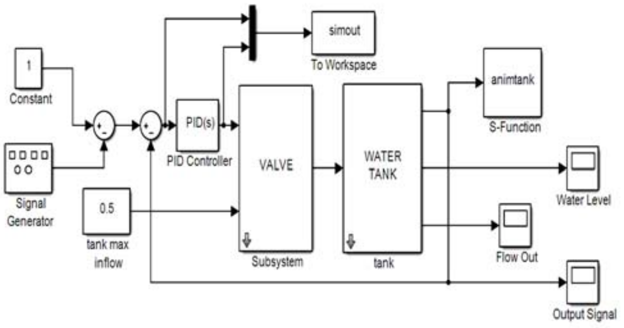


Fig. 6. Simulink the Block diagram PID Controller

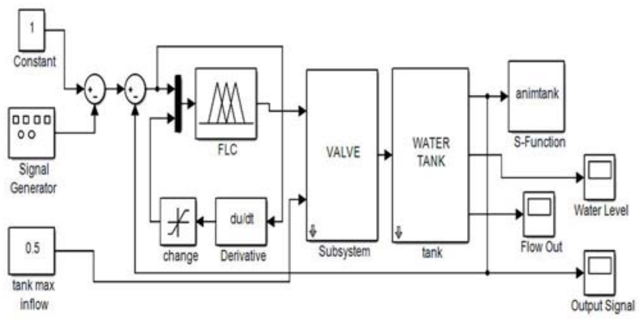


Fig. 7. Simulink the Fuzzy Block diagram

B. Fuzzy Logic Controller (FLC)

Fuzzy Logic Controller is a controller that refers to the fact that the logic involved can handle concepts that cannot be stated as "right" or "wrong"[14]. Fuzzy logic has the advantage that solutions to problems can be by human operators, so they can be used in controller design. The Fuzzy Block diagram can be shown in Figure 7; Fuzzy-PID

Fuzzy - Proportional Integral Derivative (Fuzzy-PID) controller is proposed which can be adjusted by bringing the tuning rules from the PID domain controller to the fuzzy Logic domain controller. Because nonlinear controllers can control nonlinear processes more efficiently, fuzzy controllers can provide better performance[15]. Fuzzy-PID Block diagram and Fuzzy-PID Block can be shown in Figure 8 and Figure 9;

C. PID-ANFIS

ANFIS was an amalgamation of the Fuzzy Inference System (FIS) mechanism described in neural network architecture. The architecture and learning procedures that underlie ANFIS were presented, which was a fuzzy inference system implemented in an adaptive network framework. Because the neural network has the advantage of being able to recognize the system through a learning process to improve adaptive parameters[16]. Comparisons with neural networks and previous work on FIS modeling were listed and discussed. The fuzzy inference system used was the Tagaki-Sugeno-Kang (TSK) fuzzy model for ease of computing. ANFIS data was are taken from PID training results data. Simulink PID-ANFIS Block diagram and the structure of ANFIS can be seen in Figure 10 and Figure 11.

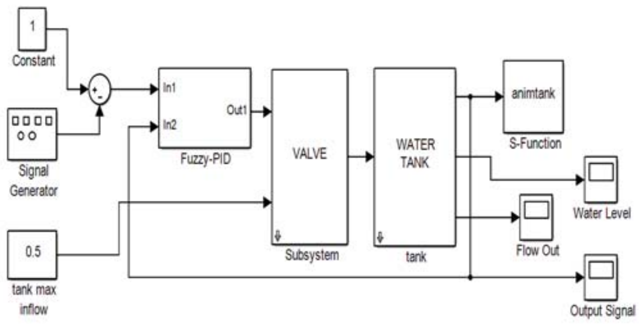


Fig. 8. Simulink the Fuzzy-PID Block diagram

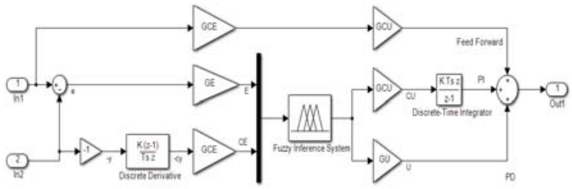


Fig. 9. Fuzzy-PID Block diagram

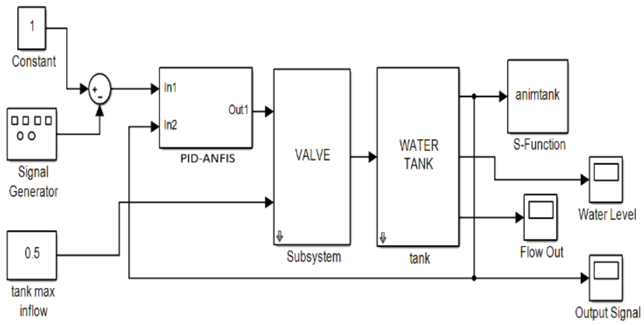


Fig. 10. Simulink the PID-ANFIS Block diagram

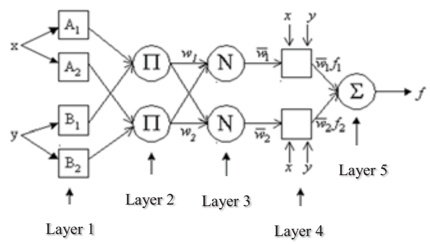
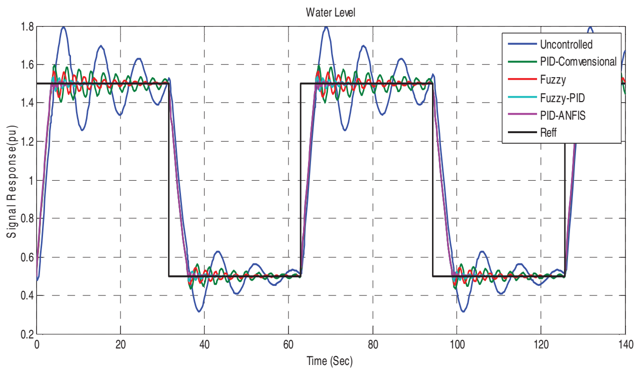


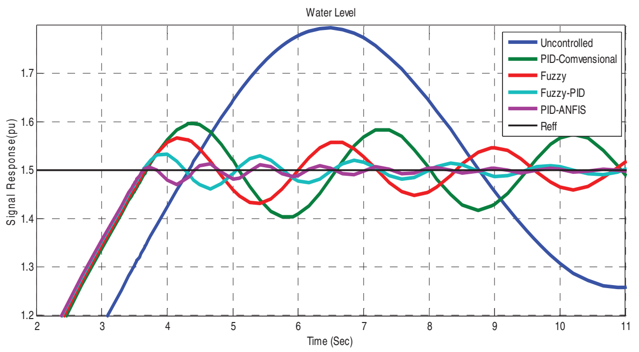
Fig. 11. The ANFIS Structure[17]

IV. RESULTS AND DISCUSSION

As many reported works regarding the PID, Fuzzy, Fuzzy-PID, and PID-ANFIS applications, these works are also developed using a designed model for the problem.In these studies, the Design of Water Level Control Systems and Output Flow Results were simulated using a diagram as shown in Figure 12 and Figure 13.

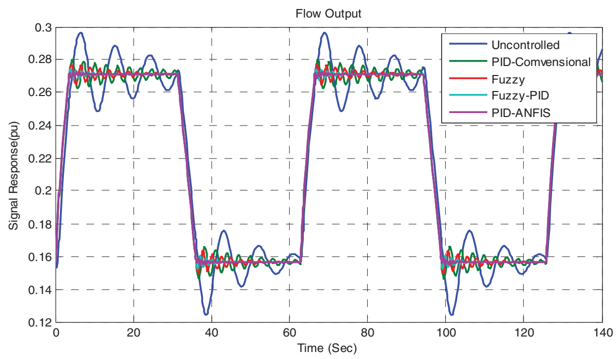


12. (a)

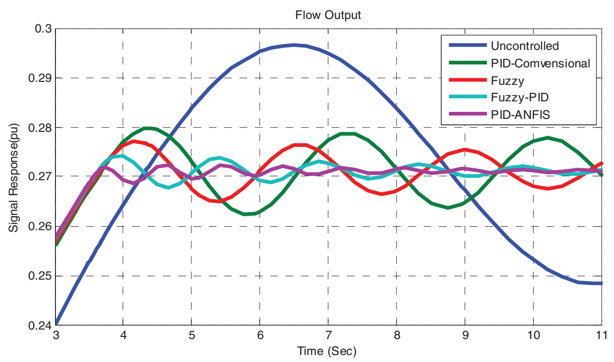


12. (b) Zoom

Fig. 12. (a) and (b) Results of Water Level Control Systems



13. (a)



13. (b) Zoom

Fig. 13. (a) and (b) Output Flow Results

From the simulation results in Figure 12. (a) and 12. (b) show the overshot, undershot, and settling time values of the water level control of various control methods. Figures 13. (a) and 13. (b) show the overshot, undershot, and settling time values of the Output Flow Results.

Table 1. Overshot and Undershot

	Un-controlled	PID	Fuzzy	Fuzzy-PID	PID-ANFIS
Overshot Water level	0.7949	0.5974	0.5670	0.5342	**0.5135**
Undershot Water level	0.7454	0.5950	0.5685	0.5371	**0.5291**
Overshot Flow	0.0184	0.0098	0.0071	0.0042	**0.0023**
Undershot Flow	0.0217	0.0076	0.0052	0.0023	**0.0014**

Overshot, Undershot, and Settling Time values can be seen in Table 1.

V. Conclusion

From the water level control simulation results obtained the smallest overshot value in the PID-ANFIS model = 0.5135 pu, the smallest undershot in the PID-ANFIS = 0.5291 pu, and the output Flow result obtained the smallest overshot value in the PID-ANFIS model = 0.0023 pu, the smallest undershot in the model PID-ANFIS = 0.0014 pu. Thus it can be concluded that the best controller model is PID-ANFIS.

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