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Synthesis water level control by fuzzy logic

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ABSTRACT

Purpose: This paper focuses on evolving of two types fuzzy and classical PID liquid level controller and examining whether they are better able to handle modelling uncertainties. A two stage strategy is employed to design the synthesis fuzzy and classical PID controller with the process of the first and second order and implements disorder (quadratic function).
Design/methodology/approach: The synthesis of fuzzy and classical PID liquid level controller was realized with the HP laptop 6830s Compaq NA779ES, software Matlab/Simulink 2008b, FIS (Fuzzy Inference System) soft logical tool, input-output unit 500 Dragon Rider and ultrasonic sensor. Using the simulation program Matlab/Simulink/FIS we simulate the operation of fuzzy and classical controller in the liquid level regulating cycle and made a comparison between fuzzy and classical controller functioning.
Findings: From the responses to step fuzzy and classical controller for first-order process shows that the actual value of the controlled variable takes the value one. Fuzzy and classical PID controller does not allow control derogation, which is also inappropriate for fuzzy and classical control cycle with incorporating disturbance. Classical PID controller in the first-order process provides short-term regulation, such as fuzzy PID controller. In fuzzy control cycle with fuzzy PID controller and incorporating disturbance in the process of second-order the control cycle is stable and at certain predetermined parameters (integral gain) a control does not allow deviations.
Research limitations/implications: In future research, the robustness of the fuzzy logic controller will be investigated in more details.
Practical implications: Using fuzzy liquid level controller can reduce power consumption by 25%.
Originality/value: Fuzzy logic controller is useful in applications of nonlinear static characteristic, where classical methods with usually classical PID controllers cannot be a satisfactory outcome.
Keywords: Automation engineering processes; Controller; Fuzzy logic; Synthesis

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1. Introduction

In the control technique very often face complex dynamic systems with nonlinear or time-variable behavior [1]. Therefore, such a process is difficult to determine in the model, since it can be inaccurate and therefore often useless [2]. Keeping these problematic processes take place mainly on the basis of human experience and its direct intervention in the process. The various parameters in the process of industrial are controlled such as temperature, level, and etc. Some process needs to keep the liquid level in the horizontal tank such as oil, chemical liquid in its. Fuzzy controllers are able to summarize human knowledge of the system and integrate them to the laws of control. This is possible by solving management problems, without creating a precise model required by classical control engineering [3]. This is the reason that the use of fuzzy logic took hold mainly in control engineering. In the field of automation technology to meet the following major areas of application, summarized in the next indent:

- Fuzzy–PID cascade controller to control the level of horizontal tank that has diameter 300 mm and 480 mm long. Interface card module PCI-6024E in computer and Lab View software program is used to built the cascade controller. Structure of its where the inner loop is a PID controller for regulating flow rate of system and outer loop is a Fuzzy logic controller for control the water level (Figure 1).

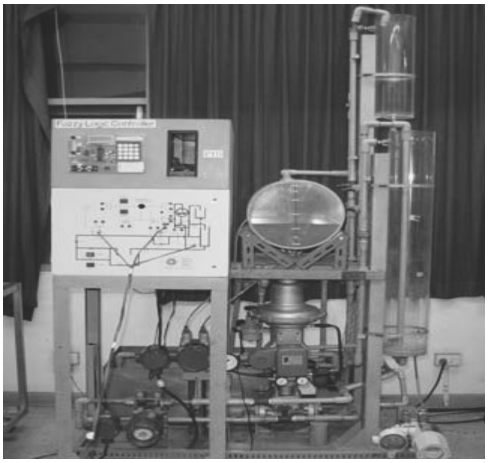

Fig. 1. Plant level control set up

- Canadian company NPH (National Plastic Sensor heater) in the global market offers temperature control with fuzzy logic to provide precise control of temperature processes. In the case where the control module (fuzzy controller) detects a failure in the process, that the decision using fuzzy logic process returns to a stable state (Figure 2).

Fig. 2. Fuzzy temperature controller

- There are intelligent fuzzy controllers (Fuzzy Logic Control; FLC), which are designed so that they can regulate the temperature of steam in thermal power plants. Temperature control is the most demanding process control loop for steam. The results showed that the FLC gives better results than conventional proportional-integral-differential (PID) controller. The main advantages are the reduction of overshoot and stricter regulation of steam temperature. FLC regulator has a very good result for complex nonlinear dynamic processes.
- A fuzzy logic based control method reduces the amount of water used by a washing machine or dishwasher during a cycle. There is a characteristic oscillation of the magnitude of the motor current as the pump cavitates during this operation, which diminishes when the washer is properly filled. By using fuzzy logic to sense this point of diminished or ceased cavitation and shutting off the incoming water, substantial savings of water can be achieved.

Using fuzzy logic in industrial applications in recent years increase. Japanese industry has launched an aggressive marketing of fuzzy ideas in the form of the first commercial outputs [4]. In the field of automation technology to meet the following major areas of application, summarized in the next indent.

2. Design fuzzy and classical PID controller, assumptions, experiments etc.

2.1. Design fuzzy and classical PID controller through software and hardware components

Using graphical tools in Simulink of Matlab subsystem, FIS (Fuzzy inference system) and input-output unit (Dragon Rider 500), which is used to capture data from the ultrasonic sensor, we designed a water level model of the process (first and second order) through the classical PID controller (Figure 3). Following the successful design of a simulation process to regulate the water level of the first and second order, with the help of configuration parameters (proportional gain, differential gain, integral gain, integrating time, and differential time) we optimize the option to set the classical regulatory system (classical PID controller), [5]. If the quality of fuzzy regulation is not sufficient to meet our needs, we repeat the design of the regulator as long, as we achieve the satisfy results. Simulations of fuzzy and classical regulators were held on a laptop through a virtual block (VR sink) in the software subsystem Simulink.

Hardware consists of the following components:

- Notebook HP Compaq 6830s NA779ES,
- Input-output unit Dragon Rider 500,
- Ultrasonic sensor (Range Finder - Maxbotix LV-WR1),
- Valve,
- Water pump.

Hardware consists of the HP Compaq 6830s Notebook NA779ES. A HP 6830s Laptop has a 3 GB DDR2 800 MHz memory, expandable to 8 GB. Hard Drive has capacity of 320 GB, supports SMART SATA bus communicates and operates plants in 5400 in a minute.

As input-output unit, we chose Dragon Rider 500 which can be programmed a wide range of Atmel microcontroller type. Via USB and RS-232 interface can communicate with a laptop HP Compaq 6830s in which the liquid level data-loading in the water tank through ultrasonic sensor.

Ultrasonic sensor is the new, weather resistant, field-hardened WR1 from Maxbotix. The WR1 uses a robust PVC housing, is

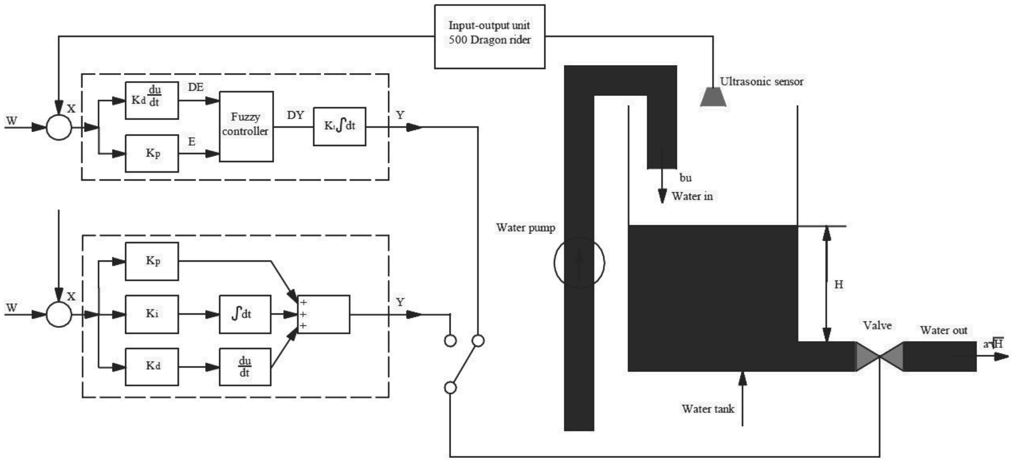

Fig. 3. Liquid level model process with fuzzy and classical PID controller

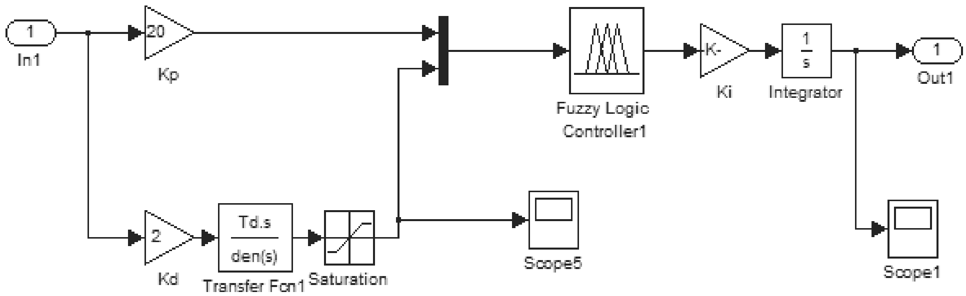

Fig. 4. Fuzzy PID controller designed using Simulink tools

designed to meet IP67 water intrusion, and matches standard electrical 3/4" PVC pipe fittings. The serial interface is a bit odd (it's RS232 instead of standard TTL), but the PWM and Analog interfaces will allow any micro to listen easily enough. The sensor provides very accurate readings of 0 to 254 inches (0 to 6.45 m) in 1 inch increments with little or no dead zone.

2.2. Fuzzy PID controller

With the help of Matlab and its subsystems (Simulink, FIS) was designed fuzzy PID controller. For the final comparative analysis, we designed a classical PID controller using the same tools (Figure 8). We conducted synthesis (simulation) fuzzy PID controller with two input linguistic variables (E; control error, DE; outflow regulating tolerance) and one output linguistic variable (Y; valve position in volts). We have for the fuzzy PID controller in the first method (softening) planning process choose a simple shape membership functions (triangular, trapezoidal, ...) input and output linguistic variables. In the second procedure (inference), we design an appropriate fuzzy rule written in matrix form. Through the third procedure (walls) we calculate the sharp, applied greatness in control technology, which can be controlled by an executive body (valve device). After completing the design fuzzy controller in the basic structure of the liquid level control cycle a simulation operation fuzzy logic system and do a comparative analysis among classical regulators. In carrying out simulations on a laptop screen time response drew comparison fuzzy and classical regulation. In case of unsatisfactory results, we changed the system of fuzzy membership functions write new rules in a matrix form, and changing the gain factor (K_p; proportional gain, K_d; differential gain, K_i; integral gain). In the classical regulator we are changing the gain factor (K_p, K_d, K_i) and temporal variables (T_d; differential time, T_i; integral time).

2.3. Modelling of closed-loop process with fuzzy PID controller through FIS and Simulink tools

Fuzzy PID controller designed using Simulink tools FIS (Figure 4) can be viewed as a regulator of the nonlinear static characteristic and the proportional gain, differential gain and integral gain. Terms nonlinearity is dependent on fuzzy PID controller of the rule base and membership functions of input (E, DE) and output linguistic variables (Y).

We are all serving to illustrate the simple case of liquid level control. To this end, we have in the programming tool Matlab/Simulink modeled 2008b simple closed-loop of liquid level control loop with the associated differential equation and also second-order transfer function, for the height of water in the tank, fuzzy PID controller (Figure 8) and a model with incorporating quadratic function (Figure 9). The differential equation representing the water level process of the first order, therefore we make the normalization of control error in meter (example; 0 to 1 m) and record them with equation (the equation of the first order transfer function lasts):

$$A \cdot (dH/dt) = b \cdot u - a \cdot \sqrt{H} \qquad (1)$$

where:
- A [m^2] – cross-sectional area of the tank
- H [m] – water level
- b – constant related to the flow rate into the tank
- u [V] – voltage of the motor of the rotary-pump
- a – constant related to the flow rate out of the tank

The equation of second-order transfer function lasts:

$$F(s) = 1/(25s^2 + 5s + 1) \qquad (2)$$

where:
- $F(s)$ – transfer function
- s – operator

Optimizing fuzzy controller we begin with the process of softening of the two inputs and one output linguistic variables. The first entry in the fuzzy controller is represented linguistic variable E, which we write with the equation:

$$E = K_p \cdot (W - X) \qquad (3)$$

where:
- E [V] – control error (in the fuzzy controller input)
- W [V] – desired value of controlled variable
- X [V] – actual (measured) value of controlled variable
- K_p – proportional gain, constant

Other input in the fuzzy controller is represented linguistic variable DE, which was written by the equation:

$$DE = K_d \cdot (dE/dt) \qquad (4)$$

where:
- DE [V/s] – time derivative of regulating tolerance
- E [V] – control error
- t [s] – time
- K_d – differential gain, constant

PID fuzzy controller model in Figure 3 is similar to the model of fuzzy PD controller. Model differs only in the definition of output fuzzy variables, which in the case of PD controller differential output (DY), which is written by the equation:

$$DY = K_d \cdot DE + K_p \cdot E \qquad (5)$$

where:
- DY [V/s] – differential output
- K_d – differential gain, constant
- DE [V/s] – time derivative of regulating tolerance
- K_P – proportional gain, constant
- E [V] – control error

Output (Y) fuzzy PID controller we get with additional dynamic Article (integrator). Linguistic variables (E, DE and Y) we with FIS tools described by five membership functions triangular (Figures 5 and 6). Membership functions were presented with linguistic values described in Table 1.

After completing the process of softening the two inputs and one output linguistic variable we continued with the inference process (decision making). The procedure was performed so that we write a set of rules in a matrix format (Table 2).

The importance of linguistic value rates shows Table 1. Language description of the system (fuzzy PID controller), we have made with shape rules "IF-THEN". We have 25 rules, which we have entered into the tool FIS (Rule Editor, Figure 7).

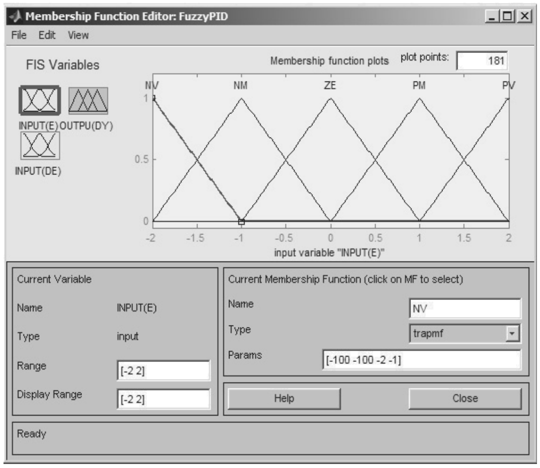

Fig. 5. Membership functions of linguistic variables E and DE

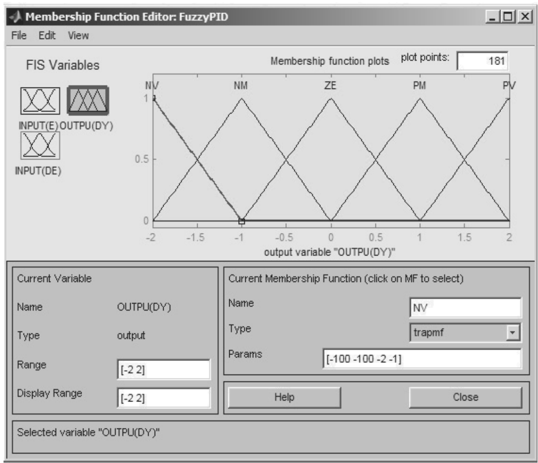

Fig. 6. Membership functions of linguistic variable Y

Table 1.
Description of the rate of linguistic value membership functions PID fuzzy controller

Linguistic value (label in the FIS)	The rate of linguistic values (describe in words)
NV	Negative high
NM	Negative little
ZE	Nothing
PM	Positive little
PV	Positive many

* The rate of linguistic values ranged between 0 and 1

Table 2.
The set of rules in a matrix format

OUTPUT (Y)		**INPUT (E)**				
		NV	**NM**	**ZE**	**PM**	**PV**
INPUT (DE)	**NV**	NV	NV	NV	NM	ZE
	NM	NV	NV	NM	ZE	PM
	ZE	NV	NM	ZE	PM	PV
	PM	NM	ZE	PM	PM	PV
	PV	ZE	PM	PV	PV	PV

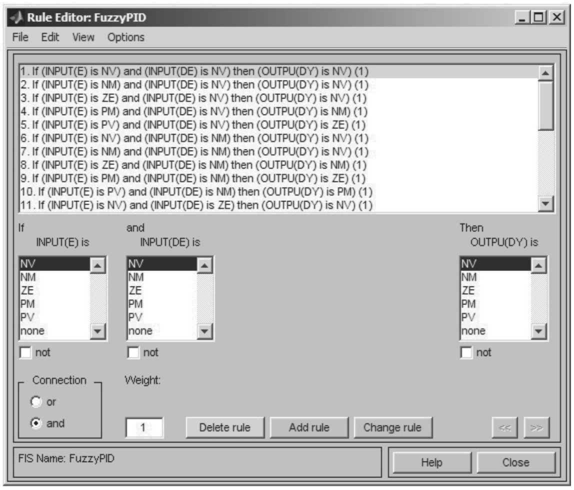

Fig. 7. Fuzzy PID controller rules

In the language of controllers for the first rule that means: if the desired value differs significantly from the measured value (liquid level) and the difference between the two further declines with high liquid level, then the control action must be high (valve should be fully open).

After the establishment of control rules in the matrix form, we designed a fuzzy control algorithm, called the inference. Inference we designed from the rules control the use of inference operators. With the help of inference rules we establish in the crowd (Table 2) fuzzy output crowd. In the application we used Mamdani inference operator [6-7], with whom we have formed membership functions sets of rules (all rules), based on output. Mamdani inference operator we set in the tool FIS. There then followed a process focus (defuzzyfication) where we choose the most used method in practice and contribute the best results. This method is called in the controller technique: Barycentric method [8-9] and we've set in the tool FIS. The method allows calculation of the sharp in control engineering useful quantities, which can be controlled enforcement valve [10-13].

After completion of the operations (fuzzification, inference, defuzzification) we completed the design of fuzzy PID controller. We carried out optimization of fuzzy PID controller, so we are taking this option to set the stability [14-15], robustness, quality of regulation and behavior changes in the proportional, differential and integral gain. Assessment of discrepancies between fuzzy PID and classical PID controller was used to determine with visually effective method in the program Matlab.

3. Description of achieved results of own researches

The results represent a correlation analysis between the fuzzy and classical PID controller in liquid level controller cycle with the process of the first and second order and incorporating disorder. Graph (Figure 10) shows the step response (normalized liquid level: 1 m) of fuzzy controller for the control loop with the corresponding process of the first order, where the proportional

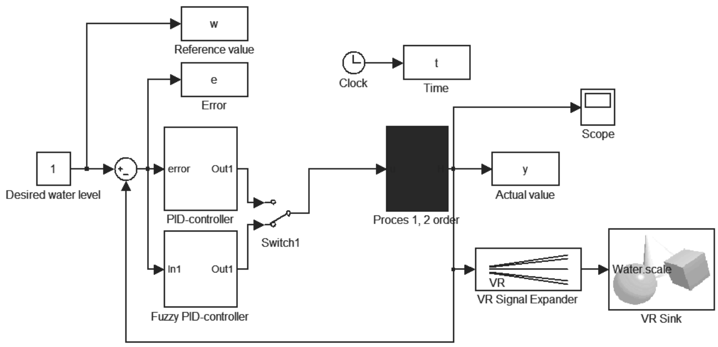

Fig. 8. Model of the closed-loop process control loop of the first and second order with fuzzy and classical PID controller

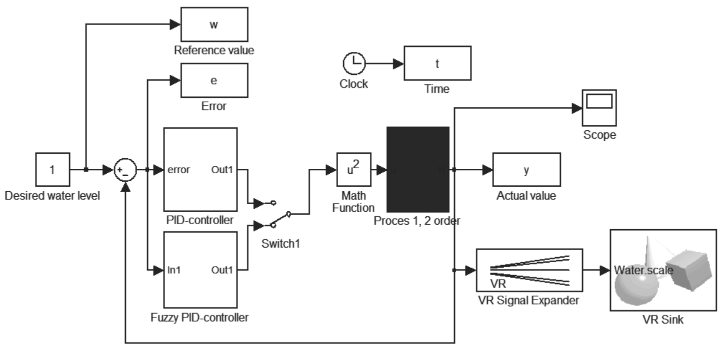

Fig. 9. Model of the closed-loop process control loop of the order with fuzzy and classical PID controller and implements disorder

gain equal; K_p = 20, differential gain; K_d = 2, integral gain; K_i = 0.01, differential time; T_d = 1 and integral time; T_i = 10. Another example given by the graph (Figure 11) shows the step response of the fuzzy controller in liquid level controller cycle with the process of first order where we have in the additional control loop implemented disorder. Graphs (Figures 12, 13, 14 and 15) show the remaining cases, which represent the step responses of the fuzzy and classical controller for liquid level control loop with process of second-order and incorporating disorder.

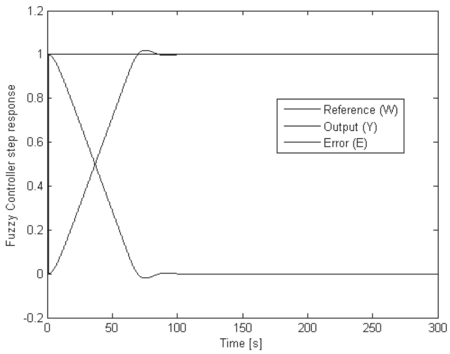

Fig. 10. Response of fuzzy PID controller on step without incorporating disturbance, order process 1

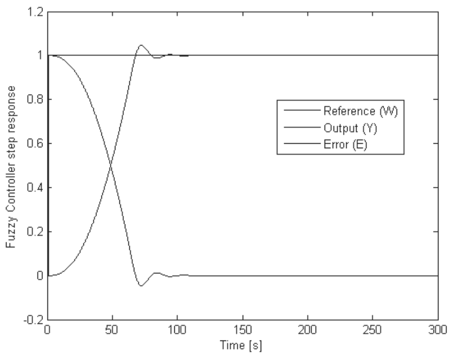

Fig. 11. Response of fuzzy PID controller on step with incorporating disturbance, order process 1

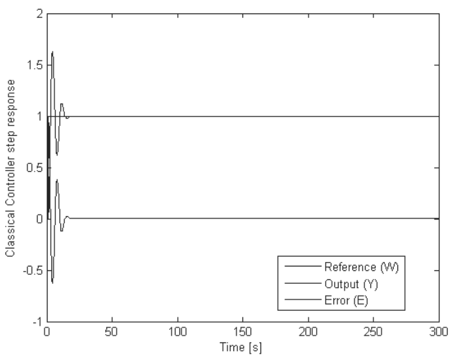

Fig. 12. Response of classical PID controller on step without incorporating disturbance, order process 2

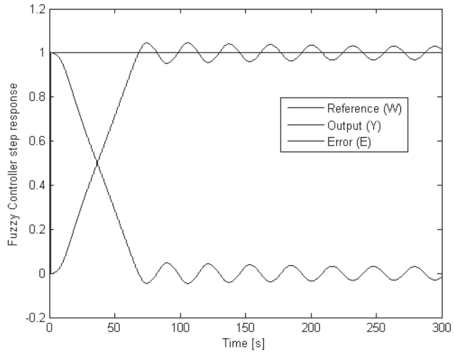

Fig. 13. Response of fuzzy PID controller on step without incorporating disturbance, order process 2, K_p = 20

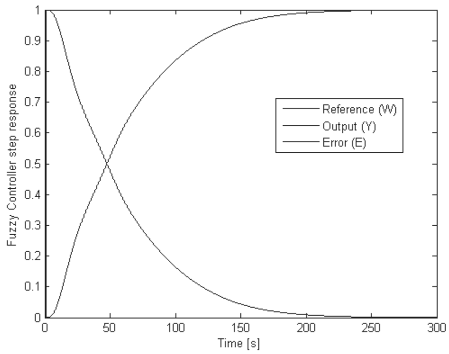

Fig. 14. Response of fuzzy PID controller on step without incorporating disturbance, order process 2, K_p = 2

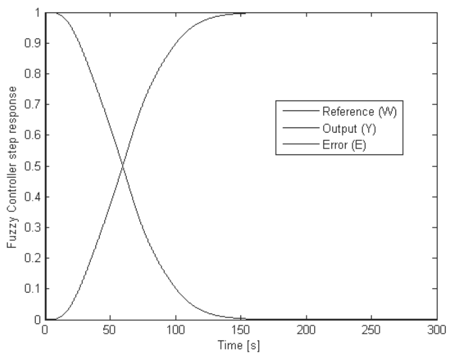

Fig. 15. Response of fuzzy PID controller on step with incorporating disturbance, order process 2, K_p = 2, K_i = 0.01

By combining the properties of P, D and I dynamic articles was designed the controller PID, characterized by a high speed, accuracy and stability of the system. From the responses to the step of fuzzy controller for first-order process Figure 10 shows that the actual value of the controlled variable takes the value one. Fuzzy controller does not allow controlling derogation, which is also inappropriate for fuzzy control cycle with incorporating disturbance (Figure 11).

In graphical responses (Figures 12 and 14) a fuzzy and the classical controller in the case of second-order process after a transitional phenomenon actual controlled variable is stabilized at the value one. This means that fuzzy and classical controllers in the case of liquid level process, does not allow control derogation.

For classical control cycle with classical PID controller and incorporating disturbance in the process of second-order control cycle becomes unstable (infinite value of the actual controlled variable). In fuzzy control cycle with fuzzy PID controller and incorporating disturbance in the process of second-order the control cycle is stable and at certain predetermined parameters (integral gain) a control does not allow deviations (Figure 15). We found that the fuzzy control systems suitable in processes where disorder is implemented but we must be careful that we correctly set the parameter controller (K_p, K_i) otherwise obtain a derogation from the reference value. The optimization of linguistic terms change the input variables, membership functions, we can improve the functioning of the fuzzy logic controller.

4. Conclusions

The result shows that fuzzy logic controller is useful in applications of nonlinear static characteristic, where classical methods with usually classical PID controllers cannot be a satisfactory outcome. This will be in the case with implements disturbance (quadratic function) in the liquid level cycle control of process second-order. Fuzzy controller allows the user apply their knowledge of the problem and transfer it to an appropriate system environment, which is close to the human way of thinking (liquid level tank control). Because this is a more complex task than just inserting a few control parameters we use a special user interface (FIS) for designing fuzzy logic applications. Fuzzy PID controller in a liquid level control process applications was proved as a very good choice, because the planning process of fuzzy controller is relatively simple and suitable for engineering practice.

Acknowledgements

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