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Design of Self-tuning PID controller using Fuzzy Logic for Level Process

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Abstract

In this paper a self-tuning PID controller is designed using fuzzy logic for a liquid level process of single tank and two tank systems. Conventional technique like Ziegler's Nichols method can be enhanced using fuzzy logic. The gain parameters that are obtained using conventional technique can be adjusted automatically using the predefined fuzzy rule set of fuzzy inference system. This paper illustrates the Comparative analysis of Ziegler's Nichols method and self-tuning Fuzzy-PID. The entire Design process and simulation is carried on MATLAB-Simulink

Keywords: Self-tuning, PID-controller, Fuzzy PID controller, Process tank, Ziegler's Nichols tuning.

Introduction

In chemical plants and oil refiners, the most important parameter that has to be controlled is level and flow of the process tank. PID controllers are the widely used controllers in process tanks related industry to control the level process variable. Mathematical expression of PID controller as follows

$U(t) = Kp*e(t)+Ki*\int e(t)+Kd*de/dt.$

Where U(t) is Control signal to the plant, Kp proportional gain, Ki Integral gain and Kd is the derivative gain. The tuning of these gain parameters Kp, Ki and Kd will cause the variations of the output response.

Table1. Comparison of Gain Parameters

	Rise time	**Settling time**	**Peak overshoot**	**Ess**
Kp	Decrease	Small variation	Increase	Decrease
Ki	Decrease	Increase	Increase	Decrease
Kd	Decrease	Decrease	Decrease	No error

From the above comparison it is clear that P-Controller improves steady state tracking accuracy, PI controller reduces steady state error and PD controller achieves steady state condition quickly. So integrating all these controllers lead to PID controller which helps to achieve set point of the plant. The gain parameters Kp, Ki and Kd of PID controllers need to be tuned well for achieving desired results. Tuning can be done by trial and error method, which is called manual tuning, needs experienced engineers to tune. In 1940 Jhon G. Ziegler and Nathaniel B. Nichols proposed Ziegler's Nichols tuning technique for tuning PID controllers till date this is widely used tuning technique. In general gain parameters can't be changed time to time with respect to error, so as a result these might exhibits undesired time domain characteristics. So employing Fuzzy logic techniques produces automatic tuning which improves the performance of the conventional tuning. The fuzzy self-tuning approach implemented on a conventional PID structure improves the dynamic as well as the static response of the system. The Fuzzy Logic control is given two inputs one is level error between the reference and actual and the second is rate of change in level error (level error derivative). And the output of the Fuzzy Logic Controller which results the gain parameters are feed to controller as their tuned gain Parameter.

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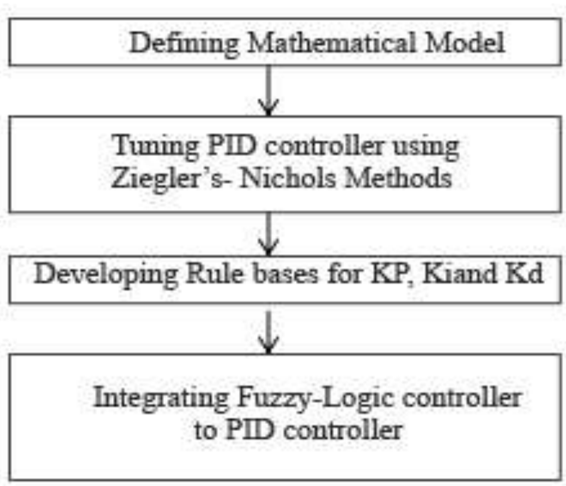

Fig:1 Work flow of the Fuzzy-PID Implementation

The above shown block diagram is the systematical work flow of this paper. The implementation of self-tuning PID controller for the liquid level process is carried on single process tank and two tank process models. Mathematical modeling of single process tank and two tank models gives the transfer functions of the entire process. The transfer function of single tank is first order system and the two tank model is second order system, gain parameters are obtained using Zeigler's Nichols method for both single and two tank process. The rule base of the fuzzy system contains membership functions for error, rate of change of error and for gain parameters. These rules are built based on the performance of the Conventional-PID. Fuzzy logic is a knowledge based system which has high degree of belongingness than normal set theory. The knowledge to the system is given in terms of membership functions (Rules) to the fuzzy inference system.

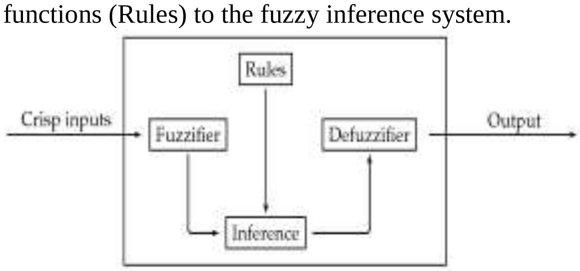

Fig:2 The block diagram of Fuzzy System

The crisp input which is nothing but physical data given to fuzzifier converts the physical data into the fuzzified data and the fuzzy inference system which process the predefined rules given to inference system as membership functions. The defuzzifier converts the fuzzified data into the physical output.

Mathematical Modeling

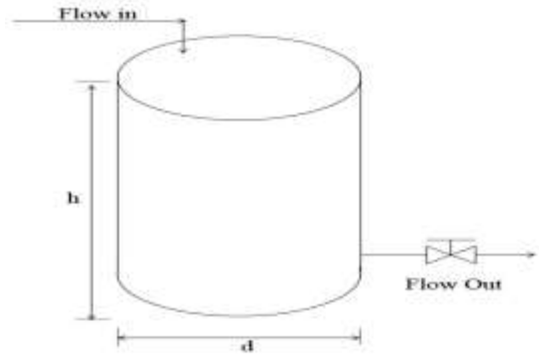

Fig.3 The single process tank level system

The Flow in and Flow out are the in-flow and the out-flow of the tank, 'h' is the level of the tank and 'd' is the diameter of the tank The in-flow of the tank tank is filled at a flow rate of F_{in} m^3/sec, The out-flow of the tank F_{out} m^3/sec. The variation of in-flow and out-flow of the tank results change in level of the tank

In-flow – Out-flow = Accumulation

Accumulation is the change of volume of the tank.

$$\text{Fin - Fout} = \frac{dh}{dt} \text{……………………1}$$

Where Fin and Fout are the in-flow and out-flow of the tank in m^3/sec

The out-flow is the head of water in the tank which is given by Δgh. The restriction of the out-flow is the presence of the valve and this can be represented by a resistance, R, larger the R value means valve less out-flow. Smaller the R value means more out-flow.

Therefore, the above equation can be rewritten as follows:

$$\text{Fin} - \frac{\Delta gh}{R}. = A\frac{dh}{dt} \text{ ………………….……2}$$

$$\text{Fin}\frac{R}{\Delta g} - h. = \frac{AR}{\Delta g}\frac{dh}{dt} \text{ ……………….…....…3}$$

$$\frac{AR}{\Delta g}\frac{dh}{dt} + h = \text{Fin}\frac{R}{\Delta g}\text{………………………...4}$$

From the equation 4 it is clear that the system looks like first order system

$$T\frac{dh}{dt} + h = K\ \text{Fin}\text{…………………….…...5}$$

Where $T = \frac{AR}{\Delta g}$ and $K = \frac{R}{\Delta g}$

If the radius of the tanks is 7meters and resistivity of out-flow is $0.92 m^3/sec$ then the transfer function of the system with an approximating first order plus dead time (FOPDT) can be as follows.

$$G(s) = \frac{0.92}{144s+1}e^{-30s}$$

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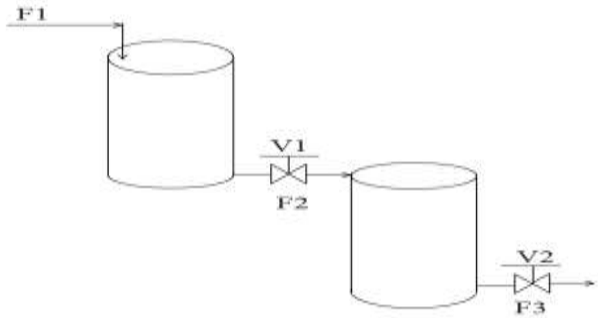

Fig.4 Two tank level system

F1 is the flow of the tank1 in m^3/sec .
F2 is the out-flow of the tank1 and inflow to the tank2 in m^3/sec .
F3 is the out-flow of the tank2 in m^3/sec
V1 & V2 are the valves of the tank1 and tank2.The above tanks are two first order tanks linked in series, with the specification of single tank the transfer function can be written with second order plus dead time (SOPDT) can be as follows

$$G(s) = \frac{0.92}{20736S^2+288S+1} e^{-30s}$$

Ziegler's Nichols tuning

The PID controller has to be tuned before implementing. Open loop tuning method is considered for single tank level system. The values of Kp is 7.4, Ki is 0.125 and Kd is 107.5 are obtained after tuning PID controller. Closed loop method of tunings is considered for tuning two tank level system. In this method the integral time Ti is set to '∞', derivative time Td as '0' and proportional gain of the PID controllers is increased in such a way that response of the system exhibits continues sustained oscillations.

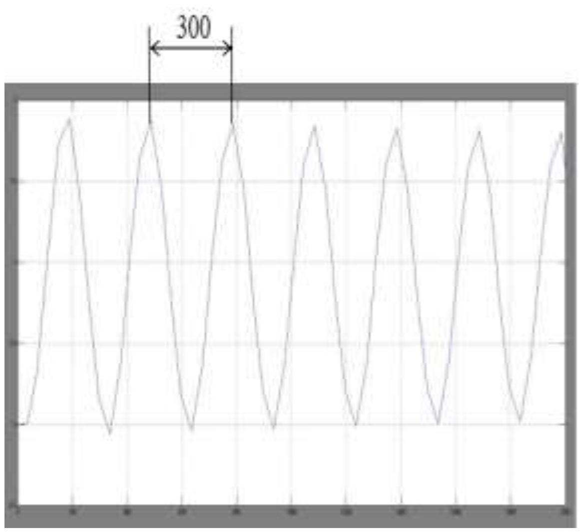

Fig.5 Ziegler's Nichols tuning method

The critical gain at which system exhibits oscillations Kcr is 11.2 and the Critical period Pcr is 300 secs.

Table.2 Ziegler–Nichols Tuning Rule Based on Kcr and Pcr (Closed loop Method)

	Kp	Ti	Td
P	0.5Kcr	∞	0
PI	0.45Kcr	$\frac{1}{1.2}$Pcr	0
PID	0.6Kcr	0.5Pcr	0.125Pcr

The Kp is 6.72, Ki is 0.046 and Kd is 262 are obtained after substituting the critical gain and critical period in Table.2

Self-Tuning Fuzzy PID controller

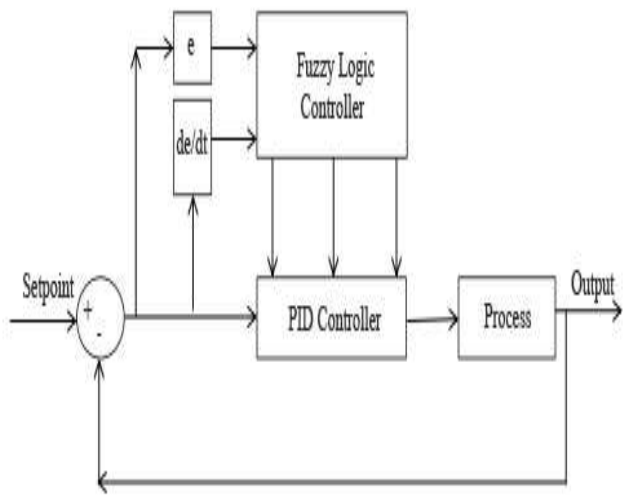

Fig.6 Block diagram of self-tuning Fuzzy PID system

As described earlier the fuzzy inference system is given two inputs one is level error and the other one is rate of change of error. The Inference system which has all predefined rules in its knowledge base results the output with respect to change of error and rate of change of error. The rules are taken in term of membership functions and this paper uses all rules as triangular membership functions.

Representation of rule Bases

The building of rule bases should be in such a way that if the rise of level is too slow with small deviation of error the Proportional gain (Kp) should be increased, if the level rises too fast with instability the Integral gain (Ki) should be increased, if the output of the system oscillates while reaching stability state the Derivative gain (Kd) should be increased.

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Table-2 Rule Base of Kp

E	EC						
	NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PM	PS	PS	ZE
NM	PB	PB	PM	PM	PS	ZE	ZE
NS	PM	PM	PM	PS	ZE	NS	NM
ZE	PM	PS	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NS	NM	NM
PM	ZE	ZE	NS	NM	NM	NM	NB
PB	ZE	NS	NS	NM	NM	NB	NB

Table-3 Rule Base of Ki

E	EC						
	NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NM	NM	ZE	ZE
NM	NB	NB	NM	NM	NS	ZE	ZE
NS	NM	NM	NS	NS	ZE	PS	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	ZE	ZE	PS	PM	PM	PB	PB
PB	ZE	ZE	PS	PM	PB	PB	PB

Table-4 Rule base for Kd

E	EC						
	NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	PS	PS	ZE	ZE	ZE	PB	ZE
NM	NS	NS	NS	NS	ZE	NS	NM
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NM	NS	ZE	PS	PM
PS	NB	NM	NS	NS	ZE	PS	PS
PM	NM	NS	NS	NS	ZE	PS	PS
PB	PS	ZE	ZE	ZE	ZE	PB	PB

From above the tables 2, 3 and 4 the rule base contains 49 rules each for three gain parameters. Where E is error, EC is the rate of change of error are the inputs to the Fuzzy controller. For example If error is NB and Ec is NB then Kp is PB, Ki is NB and Kd is PS likewise for both 7 inputs of E and Ec 49 rules can be derived. From the previous table NB- Negatively big, NM- Negatively Medium, NS- Negatively Small, ZE- Zero, PS- Positively Small, PM- Positively Medium and PB- Positively Big. Using MATLAB/Simulink all the rules are developed in Fuzzy Inference system of Simulink.

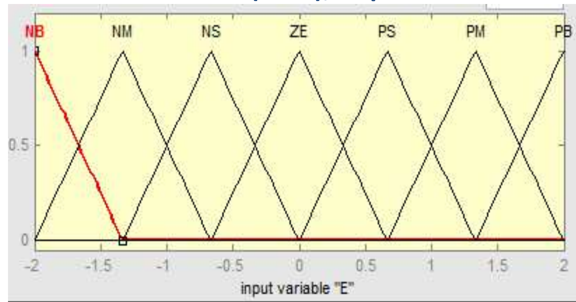

Fig.7 Membership function of error for single tank system

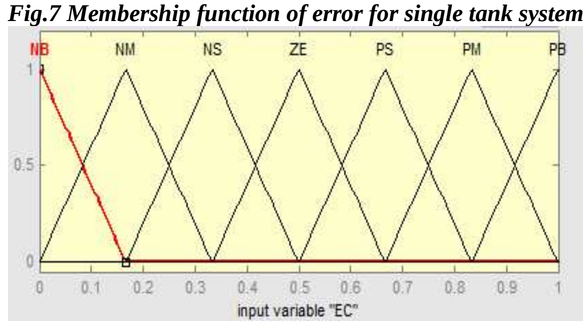

Fig.8 Membership function of rate of change of error for single tank system

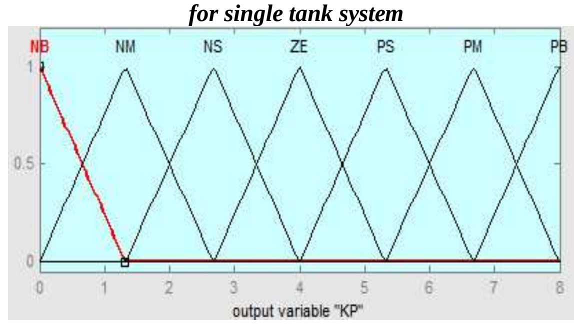

Fig.9 Membership function for Kp for single tank system

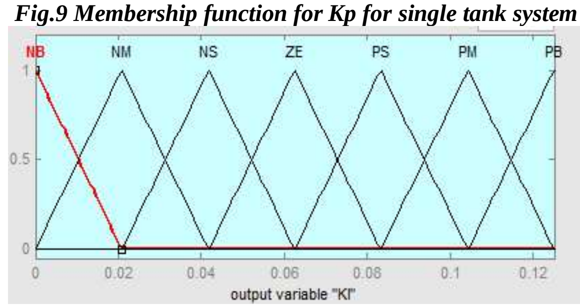

Fig.10 Membership function for Ki for single tank system

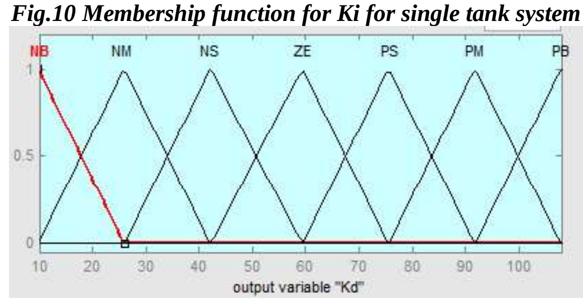

Fig.11 Membership function for Kd for single tank system

The Fig.7-Fig.11 represents the membership functions of input error, rate of change of error and

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gain parameters are declared in fuzzy inference system of fuzzy logic controller. The range for the error input is taken as [-2 2], rate of change of error is [-1 1] and for Kp the range is considered as [0 8], Ki [0.0 0.125] and for Kd [10 108]. These ranges are taken from observations of conventional PID controller since the conventional tuning gives Kp as 7.4, Ki as 0.125 and Kd as 107.5 for single tank system and in the same way for two tank system taking Ziegler's Nichols plot data as reference, the range of rule for Kp is defined as [3 7], Ki [0.01 0.045] and for Kd [200 260]. Since the Kp is 6.72, Ki is0.043 and Kd is 262 are the obtained values after Ziegler's Nichols tuning. The same rule bases are used for single and two tank systems with change in range of rule bases

Surface view of the Rule bases for Two tank syetm

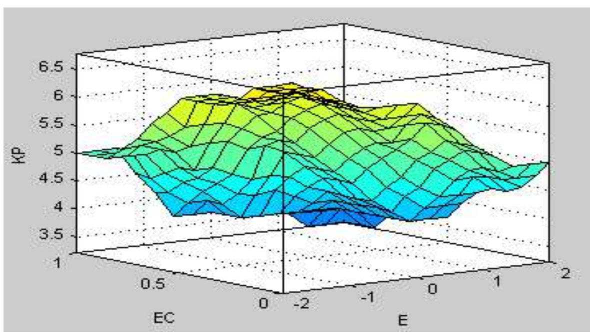

Fig.12 Surface view of Kp for two tank system

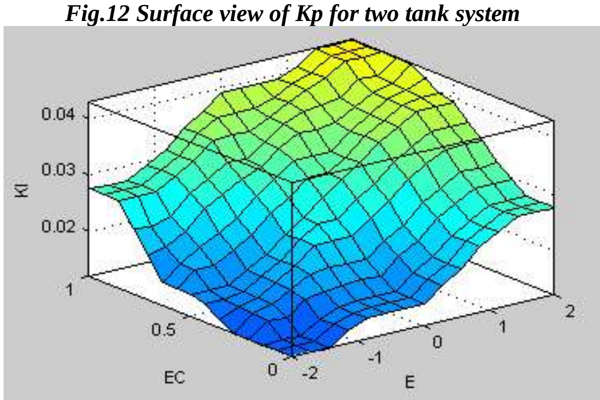

Fig.13 Surface view of Ki for two tank system

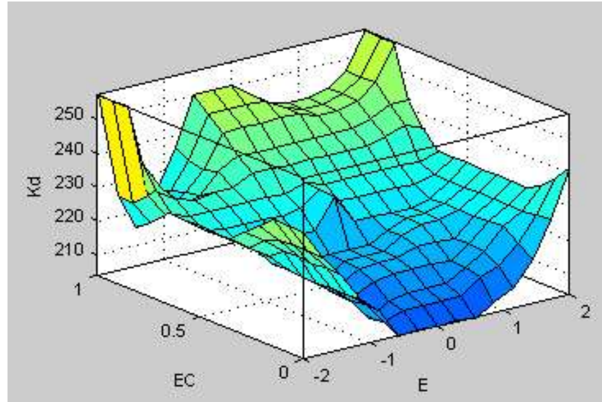

Fig.14 Surface view of Kd for two tank system

Results

Using MATLAB/Simulink for both single tank, Two tank Systems conventional PID controller and Fuzzy-PID controller are developed and Implemented and their out responses are represented as follows

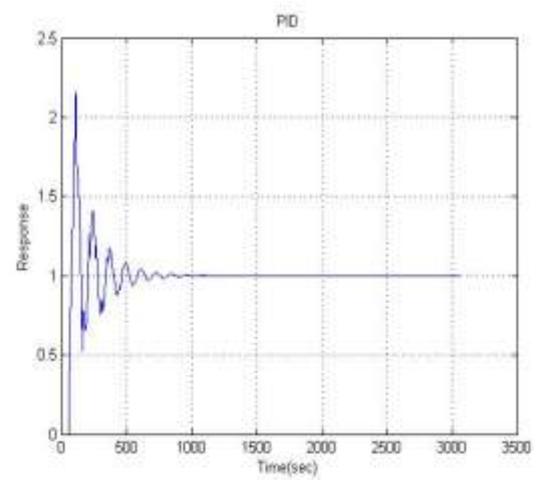

Fig.15 Output response of conventional PID Single tank system

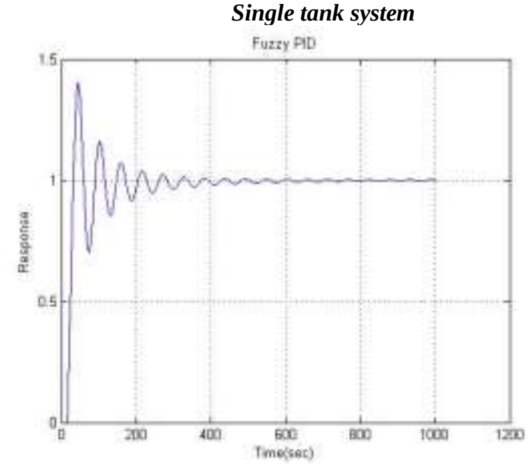

Fig.16 Output response of Fuzzy-PID Single tank system

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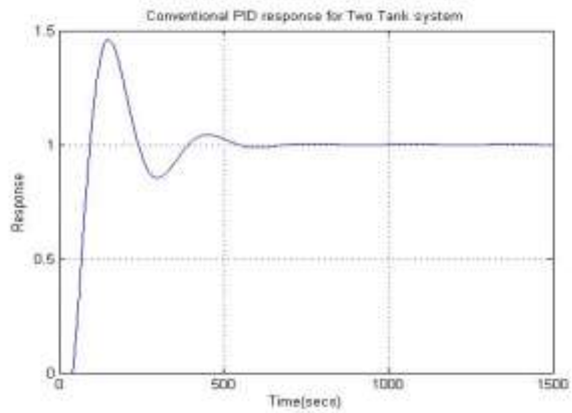

Fig.17 Output response of conventional PID Two tank system

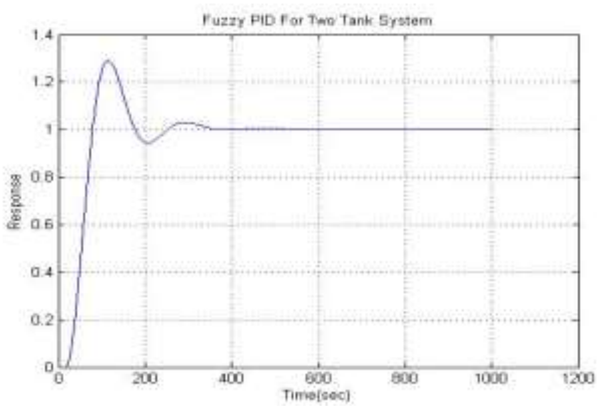

Fig.18 Output response of Fuzzy-PID Two tank system

Table.5 Comparison Time domain Specifications of Single tank system

Time domain Specifications	**Conventional PID**	**Fuzzy-PID**
Rise time(td)	12.216 sec	12.599sec
Settling time (ts)	682.44 sec	415.019sec
Overshoot (Mp)	115.9166 %	40.33 %
Peak	2.1589	1.4029
Peak time(tp)	113 sec	45 sec

Table.6 Comparison Time domain Specifications of Two tank system

Time domain Specifications	**Conventional PID**	**Fuzzy-PID**
Rise time(td)	39.393 sec	41.81 sec
Settling time (ts)	494.3097 sec	323.5 sec
Overshoot (Mp)	47.185 %	29 %
Peak	1.4718	1.2902
Peak time (tp)	148 sec	115 sec

Conclusion

The proposed approach for designing Fuzzy-PID controller in this paper gives valid results. The conventional PID with fixed gain parameters cannot satisfy this kind of requirements. Fuzzy-PID controller which can self-tune the values of the gain parameters has been successfully presented in this paper for the step response of Single tank and Two tank Liquid level systems. Using the same rule base for both Single tank and two tank systems with change of gain parameters range for both systems self-tuning mechanism can be implemented. The simulation results show that the Fuzzy- PID control system has a faster response, a lower transient overshooting, and a better dynamic performance than the conventional PID controller. The simulation results also conclude that the proposed Fuzzy-PID Controllers can also be replaced with conventional PID controller.

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