Performance Improvement of Fuzzy PID Controller Based Process Control System

K. Dhanaraju, I. Srinu, K. Satyanarayana

***Abstract* —In this paper proposes an intelligent approach (Fuzzy logic) for the design of PID controller for better disturbance rejection. The proposed PID controller is designed using pessen's tuning algorithm for rejection of different disturbances. The proposed intelligent controller has got so many advantages/features over the conventional methods. Sudden ability to reject non linear disturbances arch occur in the system during operation ,speed of operation and PID gains are altered online in accordance with the disturbances to reject. To show the efficacy of the proposed method a liquid control of process tank is considered and intelligent PID controller is designed .The designed intelligent controller is simulated under different disturbance using MATLAB/Simulink. The results are successfully verified.**

***Keywords* — Fuzzy–PID Controller, Liquid level system, PID Tuning methods MATLAB/ Simulink**

I. INTRODUCTION

The most popular controller used in the field of process control is PID controller. Lot of research has been done in the design of PID controller for controlling process parameters like Pressure, Flow, Level and etc. It was started in 1942; a scientist named Ziegler-Nichols [3] has given an algorithm to design the PID controller. But still it is a major challenge to design the PID controller**.** In many plants like in nuclear power plant, thermal power plant, chemical, maintaining the liquid level is difficult because of the disturbances in the process. Hence, it inspires all the researchers to design a better designed PID controller which can give good response even the disturbances occur in the system. The Literature has given number of algorithms to give optimal setting of PID gains, but everyone has its own limitations. Hundreds of papers have been written on tuning of PID controllers, and one must question the need for another one. These improvements on one another shall give the following justifications.

- The first justification is that PID controller is by far the most widely used control algorithm in the process industry, and that improvements in tuning of PID controller will have a significant practical impact.
- The second justification is that the simplicity in the rules and insights presented.

The First and foremost method is **Ziegler and Nichols (famous as ZN) in 1942**. [3, 4, 6]. The advantages of this method are quick and easier to use than other methods, it is robust and popular,

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and moreover it is the basis for all the improvements in the field of PID control tuning. But, it has the drawbacks in terms of poor stability margin. Pure dependency on proportional measurement to estimate I and D controllers. Approximations for the K_C, T_I, and T_D values might not be entirely accurate for different systems. It does not hold for I, D and PD controllers. The robustness of the PID controllers tuned by the Z–N method become worse as the delay becomes larger, so it should only be used for processes with small delay.

In the same year i.e. in **1942**, **Ziegler-Nichols modified [4]** his earlier method. This is based on the closed loop analysis rather in the case of previous invention. This is called as the Ultimate Cycle method. This could overcome some of the drawbacks of the earlier theory.

In **1953, G. H. Cohen G. A. Coon** [6] introduced the tuning algorithm based on the Ziegler Nichols first tuning method .One of the major drawback it should only be used for processes with small delay .The Cohen coon invention overcame t his and it can be used for systems with more time delay. The limitation of this method is it can only be used for first order models including large process delays.

Pessen's based Tuning method [4] in 1954 improved the ultimate cycle method based on the consideration of the overshoots. It is used whenever no overshoot is permitted.

Tyreus-Luben [5] tuning method is quite similar to the Ziegler –Nichols method. Therefore in this paper an intelligent PID Controller design algorithm for liquid level control process tank is proposed. The proposed intelligent controller is developed based on pessen's method which is immune to the disturbances

II.MODELING OF THE LIQUID CONTROL SYSTEM

Figure 1 shows the block diagram for liquid level control system. Here set point value is (0-5V) apply to process controller. Process controller [8] produce the control signal that signal given to V/I converter from the V/I converter we get the output is in terms of current this current given to I/P converter. This I/P converter gives the output in terms pressure it applied to control valve. Liquid level sense by using capacitance type Transmitter converts the rise or fall of the liquid to current of 4-20 mA. And this is given to I/V converter. I/V converter output in terms of voltage this value is compared with set point value [1].

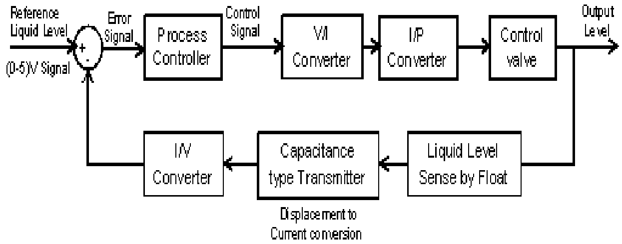

Figure1. Block diagram for liquid level control system.

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Figure.2 shows the Schematic diagram for liquid level control system. The capacitance type Transmitter converts the rise or fall of the liquid to current of (4-20) mA .and this is given to I/V converter. This I/V converter output is in terms of voltage this voltage is given to PID controller with the help of input DAQ. PID controller output is given to V/I converter with help of output DAQ. The output of V/I converter is given to I/P converter. I/P converter produce control signal to control valve based on the signal control valves are operate.

When liquid in the tank reaches the set point value, the inlet and outlet valves are closed. When the liquid in the tank is above set point value, float rises up then the inlet valve closes and outlet valve opens. When the liquid in the tank is below the set point value, float falls then the inlet valve opens and outlet valve closes. Hence, the level of the tank is maintained at constant required level.

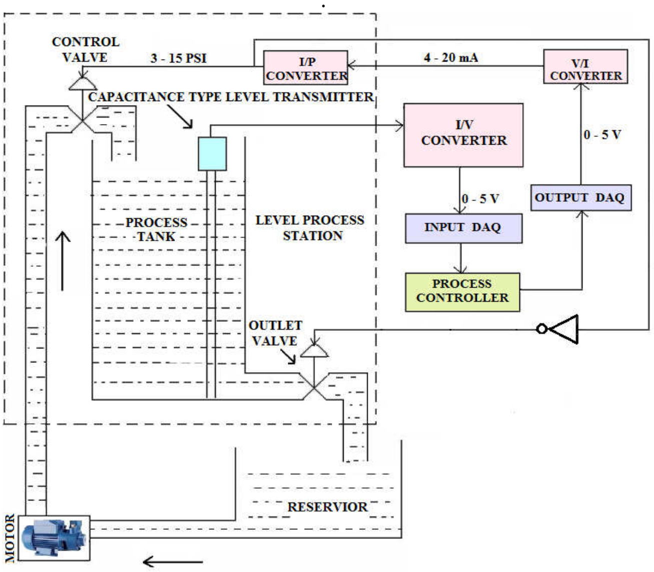

Figure2. Schematic diagram for liquid level control.

Equation.1 is the generalized transfer function for first order system.

$$G(s)=\frac{K}{TS+1}e^{-\tau S} \qquad (1)$$

The transfer function of the present liquid level is also first order which is given in equation (2).

$$G(s)=\frac{0.315}{12.826S+1}e^{-8.415S} \qquad (2)$$

Here, Delay time (τ) = 8.415 sec
Time constant (T) = 12.826 sec
Static gain (K) = 0.315

III. Pid Controller Design for Liquid Level Process Control Using Conventional Methods.

The following are some approaches for tuning of PID controller gains using conventional algorithms.

1. Open loop methods
2. Closed loop/Ultimate cycle methods

The mathematical representation of PID controller is given in equation. (3)

$$Y(t)=K_P e(t)+K_I\int_0^t e(t)dt+K_D\frac{de(t)}{dt} \text{......(3)}$$

Here

$Y(t)$ = control signal applied to the plant

K_P = Proportional Gain

T_I = Integral time

T_D = Derivative time

$K_I=\frac{K_P}{T_I}$ = Integral Gain

$K_D=K_P*T_D$=Derivative Gain.

Open loop methods:

Process reaction curve methods are also called as Open loop methods. Those methods are Discussed in this paper are as follows.

- Cohen-Coon
- Open loop transient response method

The generalized procedure for open loop methods

Step-1: Simulate the liquid level control circuit using process reaction curve method through MATLAB/Simulink as shown in Figure3.

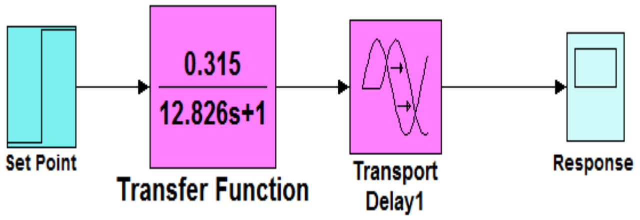

Figure3. MATLAB/Simulink model for liquid level control using process reaction curve.

Step-2: Apply the a step input signal to Simulink model and observe the system response this response is called process reaction curve as shown in figure.4

Step-3: Draw the tangent to the process reaction curve at the inflection point.

Step-4: Note the value of lag time (L), process reaction time (T).

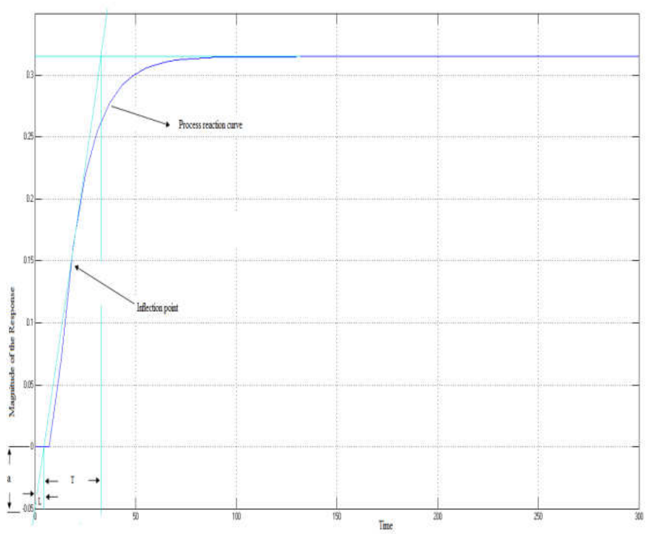

Figure4. Process reaction curve for open loop method.

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Step-5: Calculate the PID gains parameters based on tuning formula.

$$K_p = \frac{1.35}{a}\left[1+\frac{0.18\tau}{(1-\tau)}\right], T_I = \frac{2.5-2\tau}{1-0.39\tau}L$$

$$T_D = \frac{0.37-0.37\tau}{1-0.87\tau}L \quad K_I = \frac{K_P}{T_I} \quad K_D = K_P * T_D$$

Figure.5 shows the simulation model for the system designed with Cohen-Coon open loop method. Similarly simulation is done for open loop transient response method.

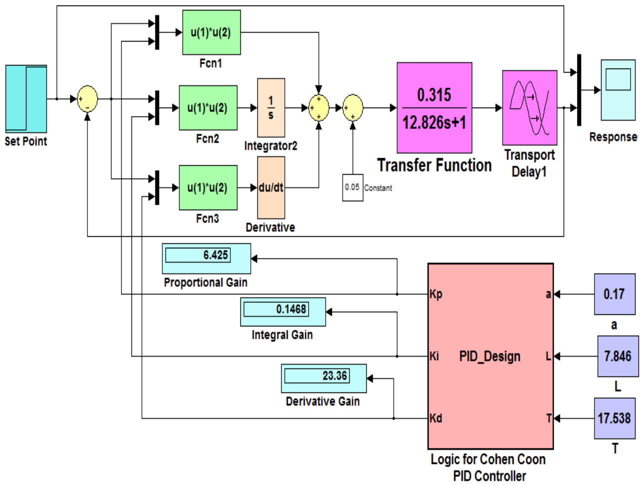

Figure5. MATLAB/Simulink model for liquid level control using Cohen-coon PID tuning method.

Closed loop/Ultimate cycle methods*:* Ultimate cycle methods are also called as closed loop/Ultimate Gain methods. Those methods are Discussed in this paper are as follows.

- Ziegler–Nichols Closed-Loop
- Modified Ziegler–Nichols
- Pessen's
- Tyreus-Luyben

The generalized procedure for closed loop methods

Step-1: Simulate the liquid level control circuit using closed loop method through MATLAB/Simulink with proportional (P) controller with unity feedback as shown in Figure 6.

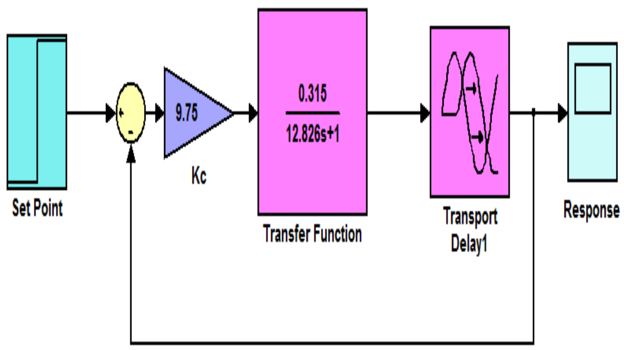

Figure6. MATLAB/Simulink model for liquid level control using Closed loop Methods

Step-2: Change the proportional gain value until the system exhibits the sustained oscillation which is shown in figure.7

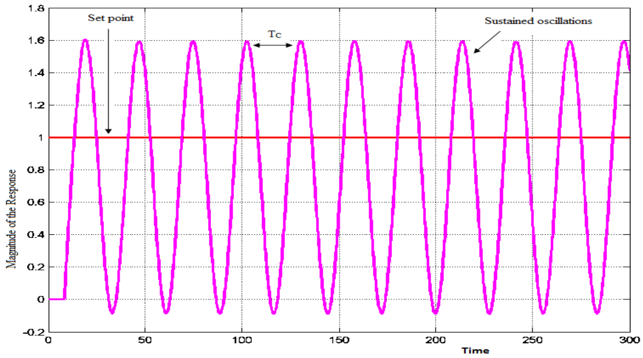

Figure7. Sustained oscillations for closed loop methods.

Step-3: This gain value represents in terms of critical gain (K_C) of the system. Note the time period of oscillations. This time represents the critical time period (T_C).

Step-4: Using K_C and T_C values, we calculate PID parameter gains based on tuning formula.

$$K_P = 0.2 * K_C$$

$$T_I = \frac{T_C}{3}, \quad T_D = \frac{T_C}{2}, \quad K_I = \frac{K_P}{T_I}$$

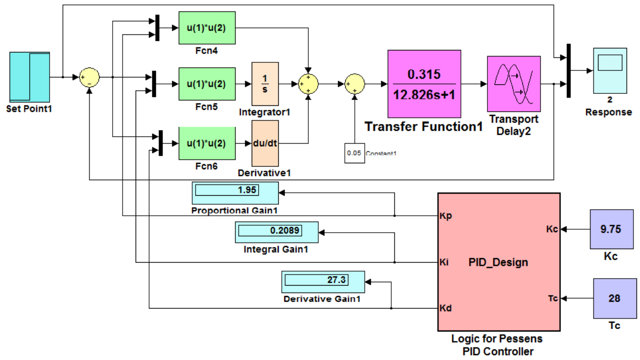

Figure8. MATLAB/Simulink model for liquid level control using pessen's method.

IV. SYSTEM DESIGN WITH FUZZY PID CONTROLLER

A. Introduction to Fuzzy Logic:

Fuzzy Logic Control (FLC) has excelled in dealing with systems that are complex, ill-defined, non-linear or time-varying. FLC is relatively easy to implement, as it usually needs no mathematical model of the control system. Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. The reason for which is very simple. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design.

System based on fuzzy logic carries out the process of decision making by incorporation of human knowledge into the system. Fuzzy inference system is the major unit of a fuzzy logic system. The fuzzy inference system formulates suitable rules and based on these rules the decisions are made. This whole process of decision making is mainly the

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combination of concepts of fuzzy set theory, fuzzy IFTHEN rules and fuzzy reasoning. The fuzzy inference system makes use of the IF-THEN statements and with the help of connectors present (such as OR and AND), necessary decision rules are constructed.

B. System Design with Fuzzy PID for disturbance rejection:

Figure.10 shows the fuzzy inference system considered for the fuzzy logic **[9, 10]** controller having disturbance as input and PID gain parameters as outputs. The membership function considered for error is shown in figure.11. After training the fuzzy PID controller, that block is inserted in the closed loop control system as shown in figure.12. This designed fuzzy logic PID controller for liquid level control system is modeled in MATLAB/Simulink. It is shown in figure.12.

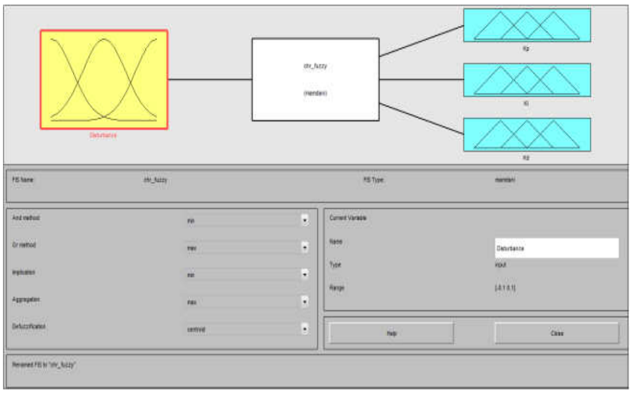

Figure9. Fuzzy Inference System (FIS) Editor

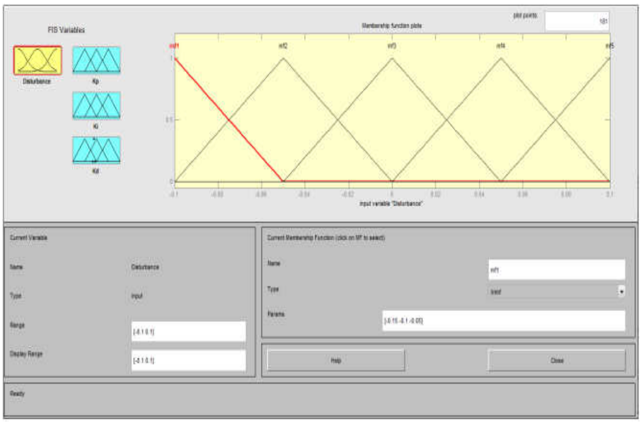

Figure10. Membership Functions.

TABLE 1. FUZZY RULES

DIS \ PID	K_P	K_I	K_D
NB	K_{P1}	K_{I1}	K_{D1}
NS	K_{P2}	K_{I2}	K_{D2}
ZO	K_{P3}	K_{I3}	K_{D3}
PS	K_{P4}	K_{I4}	K_{D4}
PB	K_{P5}	K_{I5}	K_{D5}

Table 1. Shows the Five fuzzy sets for each input and outputs: NB NS, ZO, PS, and PB.

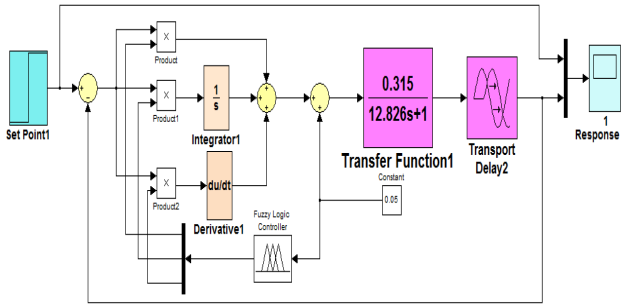

Figure11. MATLAB/Simulink model for liquid level control system design with Fuzzy-PID controller.

V. SIMULATION RESULTS

Figure.12 shows the comparison of time responses of the system designed with different open loop tuning methods, out of two methods, Cohen-Coon method gave good step response and lesser peak overshoot.

Figure.14shows the comparison of responses of the system designed with different ultimate cycle tuning methods, among all the responses, Pessen's method gave good step response and lesser peak overshoot. Figure.16 shows the comparison of time responses of the system designed FUZZY PID with different disturbances. For all the disturbance values the response parameters are almost similarly equal. In general, in processes, there may not be a possibility of constant disturbances but random.

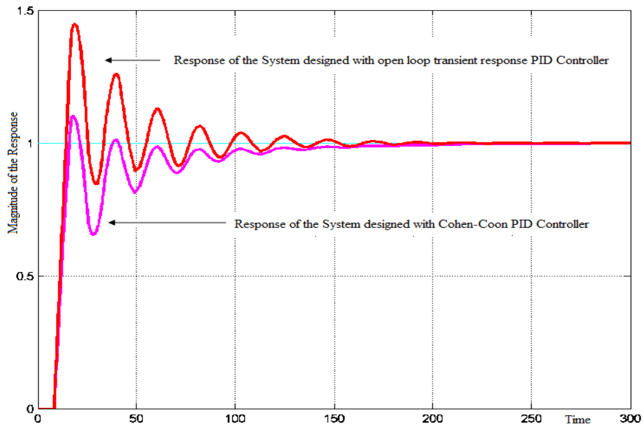

Figure12. Comparison of time responses of the system with open loop methods.

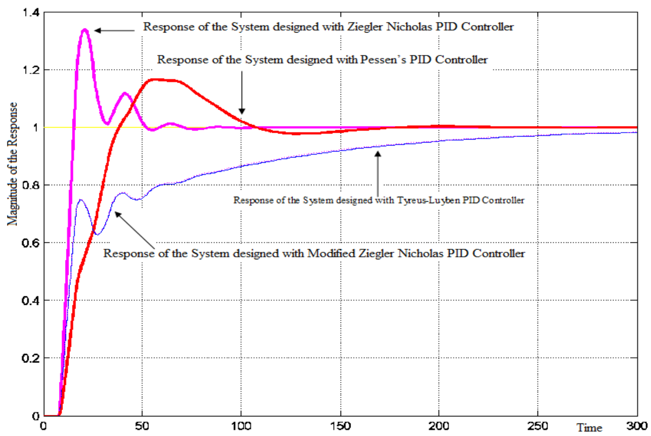

Figure13. Comparison of time responses of the system with ultimate cycle methods.

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Figure.15 shows the comparison of time responses with pessen's PID controller and FUZZY PID controller by applying random disturbance. Table 2.shows Time domain specifications of system responses with pessen's PID controller and FUZZY PID controller by applying various disturbances. We observe from table.2 the proposed FUZZY PID controller gave good results than conventional PID method.

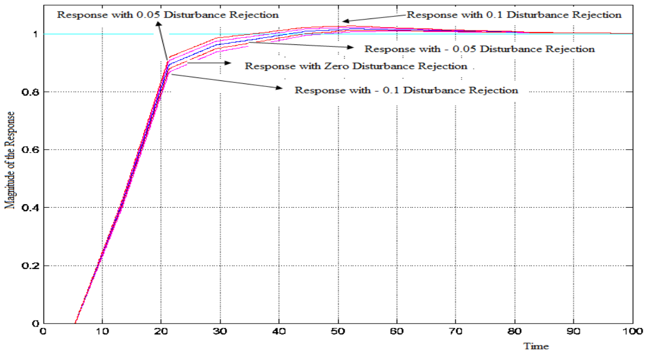

Figure14. Comparison of time responses of the system with Fuzzy PID with different disturbance.

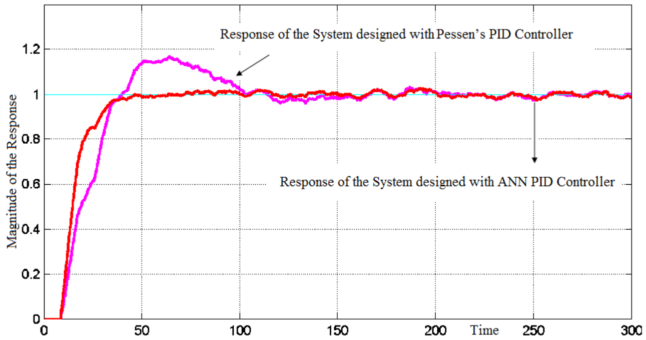

Figure15. Comparison of time responses of system with Pessen's and FUZZY PID Controller with Uniform Random Disturbance.

VI. CONCLUSION

In this paper the major drawback of conventional PID controller tuning is addressed. That is PID controller is an offline controller, tune one time and put in control circuit need to correct number of variations of errors. A single tuned PID controller can't control the nonlinear variations in error caused with respect number of disturbances/noises. Even the best method of all conventional methods (Pessen's PID for the system considered in this paper) is not able to reject the disturbance. So, in order to overcome this drawback, Intelligent Fuzzy PID controller is proposed for better Disturbance Rejection. The proposed Fuzzy PID controller is modeled and simulated in MATLAB/Simulink for liquid level control process control systems.

The time domain specifications of responses of the system with different PID controllers are given in table.2 by applying various types of disturbances. Hence, the proposed Intelligent FUZZY PID controller can tune the PID parameters online with respect to the error variations and so, effectively improves the time domain specifications. Hence, the Proposed FUZZY PID controller is best suited for liquid level controlling in a process tank.

TABLE.2 Time Domain Specifications Of System Response With Various Controllers With Various Disturbances

S. No	Type of Disturbance	Dynamic Performance Specification	for the Conventional Pessen's- PID Control System	For the FUZZY-PID Control System	Improvement from Pessen's -PID to FUZZY-PID
1	No Disturbance	Delay Time (T_D) in Sec	10.75	9.20	1.55
		Rise Time (T_R) in Sec	23.10	14	9.1
		Settling Time (T_S) in Sec	100	40	60
		Peak Overshoot (M_P) in %	16.5	1.01	15.49
		% Steady state Error	0	0	0
2	A Step Disturbance of '-0.1R'	Delay Time (T_D) in Sec	11.2	9.28	1.92
		Rise Time (T_R) in Sec	23.5	16.64	6.86
		Settling Time (T_S) in Sec	106	53	53
		Peak Overshoot (M_P) in %	16	1	15
		% Steady state Error (ESS)	0	0	0
3	A Step Disturbance of '+0.1R'	Delay Time (T_D) in Sec	10.46	9.205	1.255
		Rise Time (T_R) in Sec	22.92	13.78	9.14
		Settling Time (T_S) in Sec	100	61.93	38.07
		Peak Overshoot (M_P) in %	16.6	2.6	14
		% Steady state Error (ESS)	0	0	0
4	Pulse Generator	Delay Time (T_D) in Sec	12.5	10.8	1.7
		Rise Time (T_R) in Sec	22.5	15.5	7
		Settling Time (T_S) in Sec	100	62	38
		Peak Overshoot (M_P) in %	19.5	1.20	18.3
		% Steady state Error	0	0	0

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5	Repeating Sequence Stair	Delay Time (T_D) in Sec	11	7	4
		Rise Time (T_R) in Sec	15.5	14	1.5
		Settling Time (T_S) in Sec	110	50	60
		Peak Overshoot (M_P) in %	20.5	1.45	19.0
		% Steady state Error (ESS)	0	0	0
6	Counter Limited	Delay Time (T_D) in Sec	10	4	6
		Rise Time (T_R) in Sec	16.5	6	10.5
		Settling Time (T_S) in Sec	95	45	50
		Peak Overshoot (M_P) in %	20	1.8	18.2
		% Steady state Error (ESS)	0	0	0
7	Band Limited Noise	Delay Time (T_D) in Sec	12.5	11	1.5
		Rise Time (T_R) in Sec	23	15.5	7.5
		Settling Time (T_S) in Sec	100	50	50
		Peak Overshoot (M_P) in %	19	1.02	17.9
		% Steady state Error (ESS)	0	0	0
8	Sinusoidal Disturbance	Delay Time (T_D) in Sec	10.76	6.065	4.695
		Rise Time (T_R) in Sec	23.02	13.81	9.21
		Settling Time (T_S) in Sec	100	60	40
		Peak Overshoot (M_P) in %	16.4	2	14.4
		% Steady state Error (ESS)	0	0	0
9	Uniform Random Number	Delay Time (T_D) in Sec	10.7	6	4.7
		Rise Time (T_R) in Sec	22.65	16.7	5.95
		Settling Time (T_S) in Sec	100	54	46
		Peak Overshoot (M_P) in %	16.65	1. 2	15.45
		% Steady state Error (ESS)	0	0	0

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