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Research Paper

Design and Performance Analysis of Ann Based Hybrid Pid Controller for Liquid Level Control System

Engineering

KEYWORDS : Artificial Neural Network (ANN), Liquid level system, PID Tuning methods MATLAB/Simulink.

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ABSTRACT

In general, PID controller is designed to suit for offline conditions based on certain algorithms put in the process. But controllers used in online conditions are unable to reject the nonlinear disturbances which occur in the system during entire range operation. In order to overcome this drawback in conventional design, this paper proposes an intelligent approach like Artificial Neural Networks (ANN) for disturbance rejection in the system by designing the controller in online conditions the PID controllers gains are altered i.e. online in accordance with the disturbances to reject .The proposed intelligent PID controller design method is based on pessen's tuning algorithm for rejection of different disturbance. To validate the proposed method, a liquid level control of a process tank is considered and an intelligent PID controller is designed using the Artificial Neural Network .The designed intelligent PID controller is simulated under different disturbances using MATLAB/Simulink and results are successfully verified.

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-Nicholos [7] 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 when the disturbances occur in the system. The Literature has given number of algorithms to give optimal setting of PID gains, but every algorithm 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 [1,2,4,7,and 8]

§ The first justification is that a 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**.[7,4,10]. The advantages of this method are quick and easier to use than other methods, it is robust and popular, 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** [10] 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 [2] 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 LEVEL 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 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 [9].

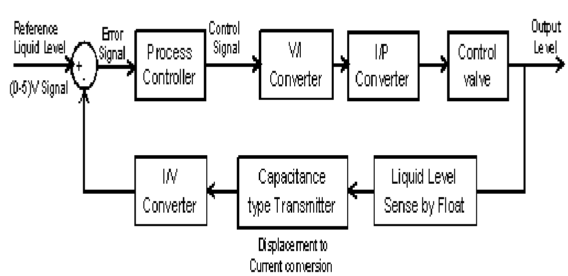

Figure.1 Block diagram for liquid level control system

Figure.2 shows the Schematic diagram for liquid level control system. The capacitance type Transmitter converts the rise or

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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.

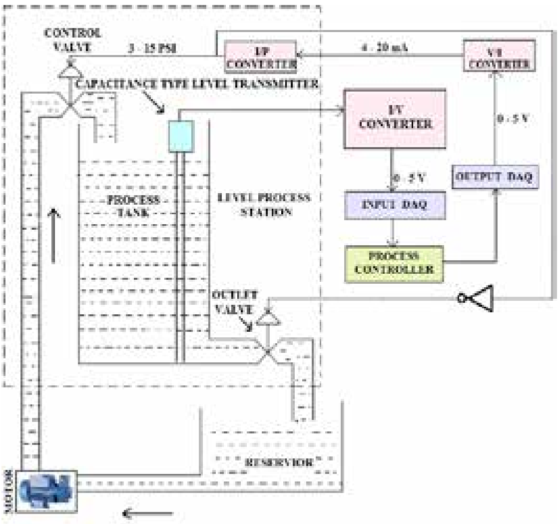

Figure.2 Schematic diagram for liquid level control

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.

A. Open loop methods
B. Closed loop/Ultimate cycle methods

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

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

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.

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.

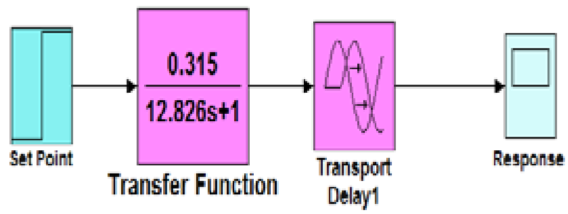

Figure3. MATLAB/Simulink model for liquid level control using process reaction curve

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).

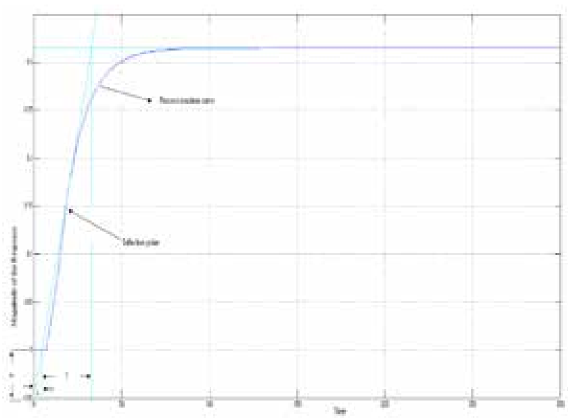

Figure.4 Process reaction curve for open loop method

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

$$K_p = \frac{1.35}{a}\left[1 + \frac{0.18\tau}{(1-\tau)}\right] \quad ....(4)$$

$$T_I = \frac{2.5-2\tau}{1-0.39\tau} L \quad ....(5)$$

$$T_D = \frac{0.37 - 0.37\tau}{1 - 0.87\tau} L \text{ ....(6)}$$

$$K_D = K_P * T_D \text{ ....(7)}$$

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.

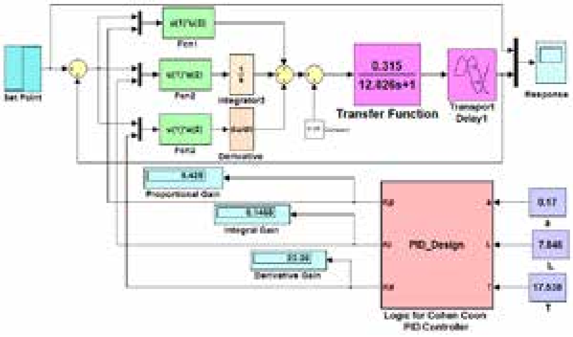

Figure5. MATLAB/Simulink model for liquid level control using Cohen-coon PID tuning method

A. **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.

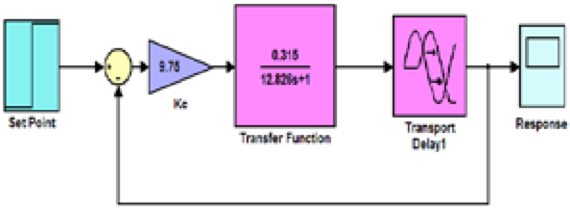

Figure6. MATLAB/Simulink model for liquid level control using Closed loop Methods

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

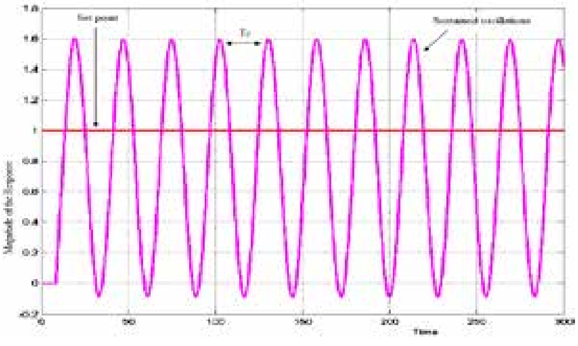

Figure.7 Sustained oscillations for closed loop methods

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.

$$K_P = 0.2 * K_C \text{ ....(8)}$$

$$T_I = \frac{T_C}{3} \text{ .... (9)}$$

$$T_D = \frac{T_C}{2} \text{ .... (10)}$$

$$K_I = \frac{K_P}{T_I} \text{ ....(11)}$$

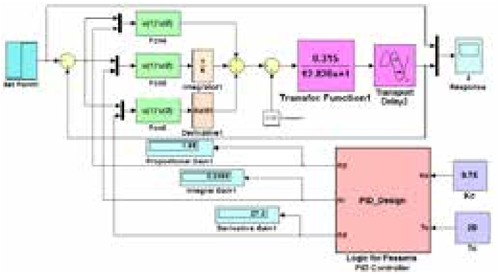

Figure8. MATLAB/Simulink model for liquid level control using pessen's method

IV SYSTEM DESIGN WITH ARTIFICIAL NEURAL NETWORK PID CONTROLLER

A Introduction to Artificial Neural Networks

Artificial Neural Networks are motivated by human nervous system because of their characteristics like fault tolerance, parallel processing of data and distributed in nature. The error change in a closed loop control system is non-linear in nature. So, it is required to update the PID gains according to the error change. Fig.9 shows the structure of biological neuron. Dendrites are small branching fibers that extend from soma or cell body. Soma or cell body contains nucleus and other structures. Axon is a single fiber that carries information away from the soma to synaptic weights of other neurons. Synapse is a point of connection between two neurons [5, 6].

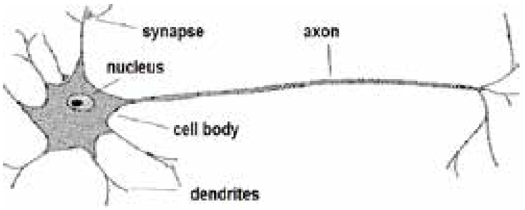

Figure.9 structure of a biological neuron

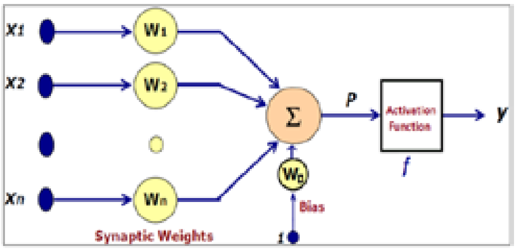

Figure.10 Mathematical model of biological neuron

Different activation functions that are commonly used are linear, tan-sigmoidal and log-sigmoidal their mathematical representations are as in equations (12-15) respective.

$$y = purelin(p) = p = \left[w_0 + \sum_{i=0}^{n} w_i x_i \right] \quad (12)$$

$$y = \tan sig(p) = \frac{2}{1+e^{-2P}} - 1 \quad (13)$$

$$y = \log sig(p) = \frac{1}{1+e^{-P}} \quad (15)$$

Neural networks can update their synaptic weights constantly according to the changes in the plant dynamics and disturbances in the plant. This paper proposes a neural network based Intelligent-PID controller for better disturbance rejection. Neural networks can auto tune the PID gain parameters by updating their connection weights as shown in fig.11

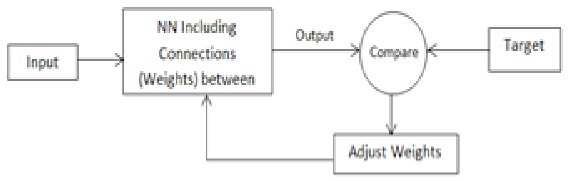

Figure.11 updating of synaptic weights of artificial neural network (ANN)

B .System design with Artificial Neural Network PID controller

The procedural steps used for the simulating the Artificial Neural Network in the MATLAB are:

Step-1: Consider the closed loop control system and apply the set point is one.

Step-2: Apply 0.1 disturbances to the plant.

Step-3: Tune the PID controller and note the PID parameters.

Step-4: Reduce the disturbance by 0.01 and tune the PID Controller for better response and note the PID gain values

Step-5: If disturbance is greater than-0.1 then proceed to step- 4.

Step-6: If else then go to next step.

Step-7: Tabulate all the PID gain parameters for corresponding disturbance values.

Step-8: Prepare the data for input and targets to save to the workspace.

Step-9: Select the architecture of the network type of the network, number of hidden layers, hidden neurons activation function and etc.

Step-10: Then configure the network.

Step-11: Initialize the synaptic weights and biases.

Step-12: Train the network.

Step-13: Finally use the network in the application.

Two layer feed forward neural network architecture is considered with 5 number of tan-sigmoidal hidden neurons and three output linear neurons. After training the network with Back Propagation Algorithm, that network is inserted in the closed loop control system which is shown in fig.12

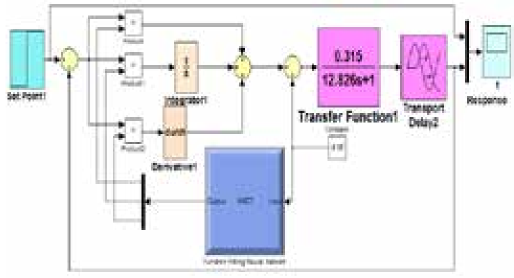

Figure.12 MATLAB/Simulink model system with Artificial Neural Networks PID controller

The performance of the ANN is analyzed by using Mean Squared Error (MSE) which is given Equation (16). Fig.13 shows the performance plot for the neural network. The error is decreasing for every epoch and reached the tolerance value.

$$MSE = \frac{\sum_{1}^{n} (X_a - X_b)^2}{n} \quad (16)$$

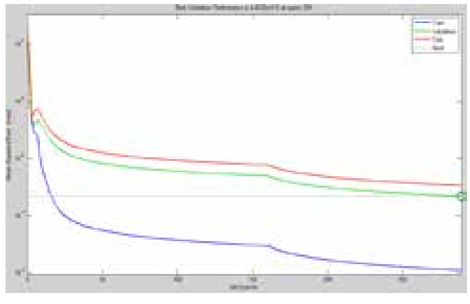

Figure.13 Performance plot for neural network

Here 'X_a' is the actual value

'X_b' is the forecasted value and

And 'n' is the total number of patterns being used.

Fig.14 shows the regression plot which gives the information how the data is fitted. The regression value (R) represents the correlation between the outputs and targets with respect to training validation and test data.

The line in the regression plot will be in 45 degree to X-axis for R=1 where the network output is equal to the target.

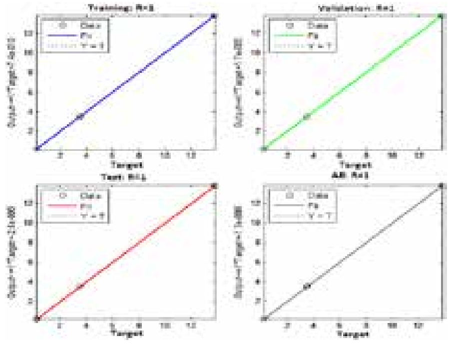

Figure.14 Regression plot for the neural network

V SIMULATION RESULTS

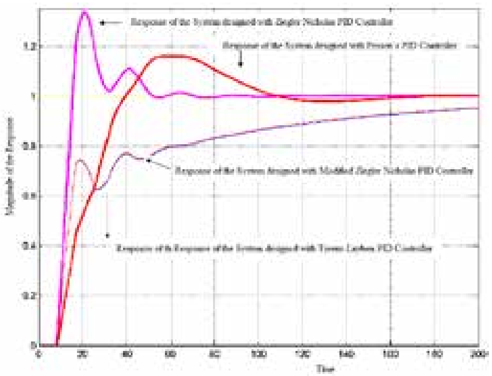

Figure.15 Comparison of time responses of the system with ultimate cycle methods

Fig.15 shows 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.

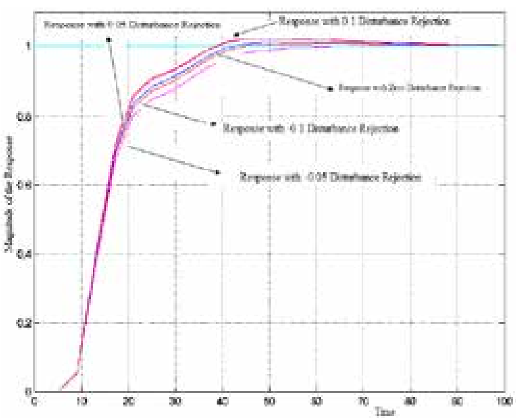

Figure.16 Comparison of time responses of the system with Artificial Neural Network PID with different disturbance

Fig.16 shows the comparison of time responses of the system designed Artificial Neural Network PID with different disturbances. For all the disturbance values the response parameters are almost similarly equal. In general, in the processes, there may not be a possibility of constant disturbances but the disturbances might occur randomly

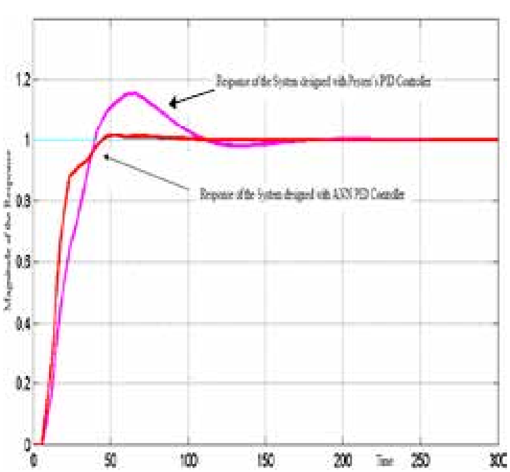

Figure.17 Comparison of responses of the system designed with Pessen's and ANN with zero disturbance.

Fig.17 to 19 shows the comparison of responses of the system designed without disturbance, with sinusoidal and uniform random number disturbance respectively which shows that the proposed ANN PID controller can reject disturbances.

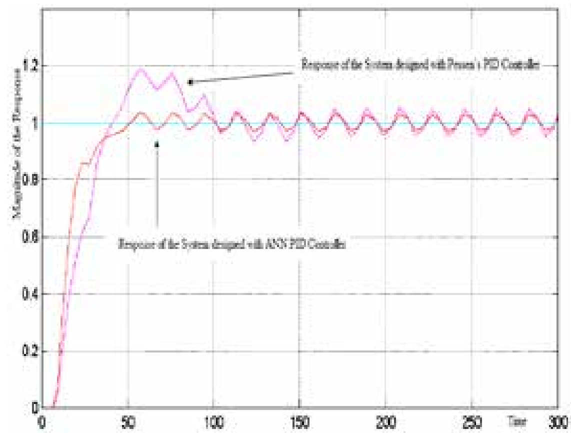

Figure.18 Comparison of time responses of system with Pessen's and Artificial Neural Network PID Controller with sinusoidal Disturbance.

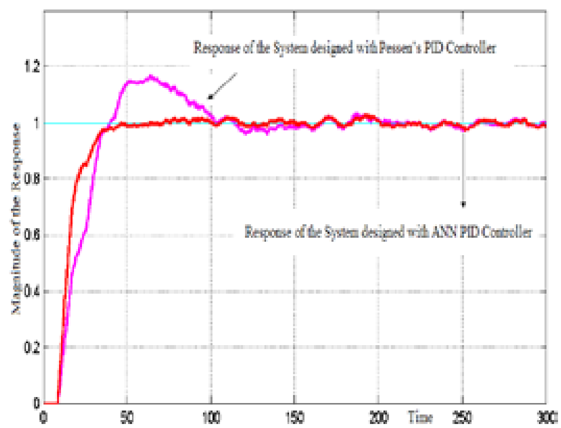

Figure.19 Comparison of responses of the system designed with Pessen's, and ANN with uniform random number disturbance.

Table .1 shows Time domain specifications of system responses with pessen's PID controller and Artificial Neural Networks PID controller by applying various disturbances. We observe from Table.1 the proposed Artificial Neural Networks PID controller gave good results than conventional PID method.

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 that needs to correct number of variations of errors. A single tuned PID controller can't control the nonlinear variations with errors caused with respect to a 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 Artificial Neural Networks PID controller is proposed for better disturbance rejection. The proposed ANN 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.1 by applying various types of disturbances. Hence, the proposed Intelligent Artificial

Neural Networks PID controller can tune the PID parameters online with respect to the error variations and so, can effectively improve the time domain specifications. Hence, the Proposed Artificial Neural Networks PID controller is best suited for liquid level controlling in a process tank.

TABLE.1TIME DOMAIN SPECIFICATIONS OF SYSTEM RESPONSES WITH VARIOUS CONTROLLERS WITH VARIOUS DISTURBANCE

S. No	Type of Disturbance	Dynamic Performance Specification	For the Conventional Pessen's-PID Control System	For the Proposed ANN-PID Control System	Improvement from Pessen's -PID to ANN-PID
1	A Step Disturbance of '-0.1R'	Delay Time (T_D) in Sec	11.2	9.45	1.75
		Rise Time (T_R) in Sec	23.5	20.52	2.98
		Settling Time (T_S) in Sec	106	48.7	57.3
		Peak Overshoot (M_P) in %	16	No overshoot	16
		% Steady state Error (ESS)	0	0	0
2	A Step Disturbance of '-0.05R'	Delay Time (T_D) in Sec	11.12	9.34	1.78
		Rise Time (T_R) in Sec	23.25	17.31	5.94
		Settling Time (T_S) in Sec	101.5	50	51.5
		Peak Overshoot (M_P) in %	16	No overshoot	16
		% Steady state Error (ESS)	0	0	0
3	No Disturbance	Delay Time (T_D) in Sec	10.75	9.35	1.4
		Rise Time (T_R) in Sec	23.10	15.97	7.13
		Settling Time (T_S) in Sec	100	51	49
		Peak Overshoot (M_P) in %	16.5	0.77	15.73
		% Steady state Error (ESS)	0	0	0
4	A Step Disturbance of '+0.1R'	Delay Time (T_D) in Sec	10.46	9.35	1.11
		Rise Time (T_R) in Sec	22.92	14.03	8.89
		Settling Time (T_S) in Sec	100	52.5	47.5
		Peak Overshoot (M_P) in %	16.6	1.69	14.91
		% Steady state Error (ESS)	0	0	0
5	A Step Disturbance of '+0.05R'	Delay Time (T_D) in Sec	10.46	9.38	1.08
		Rise Time (T_R) in Sec	23	14	9
		Settling Time (T_S) in Sec	100	52	48
		Peak Overshoot (M_P) in %	16.6	1.76	14.84
		% Steady state Error (ESS)	0	0	0
6	Uniform Random Number	Delay Time (T_D) in Sec	10.7	6.1	4.6
		Rise Time (T_R) in Sec	22.65	17.99	4.66
		Settling Time (T_S) in Sec	100	50	50
		Peak Overshoot (M_P) in %	16.65	1	15.65
		% Steady state Error (ESS)	0	0	0
7	Sinusoidal Disturbance	Delay Time (T_D) in Sec	10.76	8.5	2.26
		Rise Time (T_R) in Sec	23.02	18.51	4.479
		Settling Time (T_S) in Sec	100	54	46
		Peak Overshoot (M_P) in %	16.4	1.8	14.6
		% Steady state Error (ESS)	0	0	0

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