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A Comparison of PID Controller Tuning Methods for Three Tank Level Process

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ABSTRACT: Automatic controllers are introduced for efficient control of the process industries. Proportional, Integral and derivative (PID) controllers are the most widely used controllers in the most process industries because of their robustness, easy implementation and simplicity. Various tuning methods like Ziegler-Nichols (Z-N) method, Cohen-Coon(C-C) method, Minimum error integral criteria method and Genetic Algorithms (GAs) have been suggested for optimum setting of PID controller parameters. In this paper the performance of Genetic algorithm based PID controller is compared with conventional PID controller for various tuning techniques in the case of three tank level process control system. This comparative study is carried out for set point tracking of three tank level process using computer simulation.

Keywords: PID controller, Ziegler-Nichols, Cohen-Coon, ISE, ITAE, IAE, Genetic Algorithm, Level process

I.INTRODUCTION

In many industrial process applications the liquid level control is of much importance, especially in oil and gas industries, waste water treatment plant & food processing industries. Three tank system relates to liquid level control problems generally existing in industrial surge tanks. For example, accurate mould level control in continuous bloom casting gained substantial benefits in steel producing companies [1].The general objective of the three tank level is to track the set point and stabilize the level in the tanks with less number of oscillations and minimum settling time. The final product quality depends on the accuracy of the level controller. The objective of the controller is to reach the target and be able to track a new set point values quickly. This control problem can be solved by a number of level control strategies ranging from conventional PID to Genetic algorithm based PID controllers[2],[3],[4].In level control applications the conventional Proportional-Integral-Derivative (PID) controller is generally used, but the tuning parameters of the controllers must be estimated by tuning technique either in frequency response or time response to attain the desired performances[5],[6].Many different tuning techniques have been proposed for attaining the desired control system response. These tuning techniques are developed based on one or more than one of the control objectives as selected criterion. Many new techniques are proposed by the academic control community. One new technique is Genetic Algorithm based tuning [7]. An advantage of the GA for auto tuning is that it does not need gradient information. With this advantage Genetic Algorithm (GA) based PID controller is presently implemented in many industrial automation applications [8].

The paper has been organized as follows: Section 2 describes the modeling of three tank system. Section 3 reviews various tuning methods of PID controller. Section 4 presents simulation of the process and PID controller for different tuning methods.

II.MODELING OF A THREE TANK LEVEL CONTROL PROCESS

Three first order processes are connected in series behaves as a three tank liquid level system, and its structure is shown in Fig.1.

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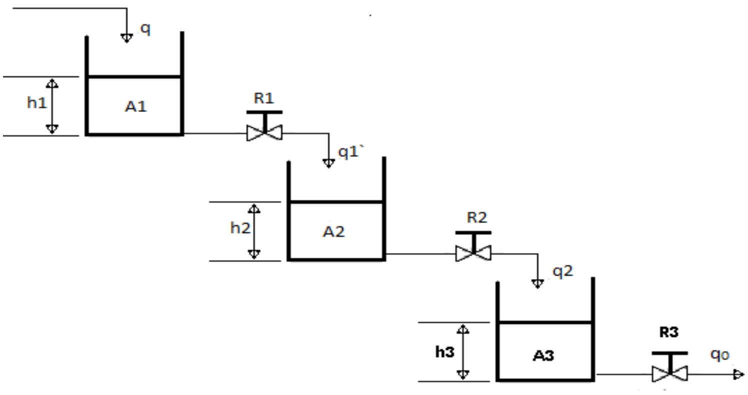

Fig.1 Three tank liquid level process

q(t) : Liquid inflow rate in tank1
$q_o(t)$: Liquid outflow rate in tank3
h_1,h_2 and h_3 : Liquid level in tanks 1,2,3 respectively
A_1,A_2 and A_3 : Area(m2) of tanks 1,2,3 respectively
For tank-1:
$q - q_1 = A_1(dh_1/dt)$ (1)
For tank-2:
$q_1 - q_2 = A_2(dh_2/dt)$ (2)
For tank-3:
$q_2 - q_0 = A_3(dh_3/dt)$ (3)
Where
$q_1= h_1/R_1$; $q_2= h_2/R_2$; $q_0= h_3/R_3$
and $T_1 = A_1R_1$; $T_2= A_2R_2$; $T_3 =A_3R_3$
Therefore, the transfer function of the above three tank system is
$G(s) = Q_0(s) / Q(s) = 1 / (1+ T_1s) (1+ T_2s) (1+ T_3s)$ (4)
By considering T1= 1sec.,T_2 = 0.5sec. and T_3 = 0.33sec.,
the overall transfer function of the three tank system is represented as
$G(s) =6/(s+1) (s+2) (s+3)$ (5)

III.PID CONTROLLER TUNING METHODS

Transfer function of the most basic form of PID controller is
$G_C(s) = P + I/s + D s = K_C (1 + 1/ T_I S + T_D S)$ (6)
Where $P = K_C$, $I = K_C/ T_I$ and $D = K_CT_D$ are tuning parameters of the PID controller.

Tuning methods of controller describe the controller parameters in the form of formulae or algorithms. They ensure that the resultant process control system would be stable and would achieve the desired objectives. In literature, a wide variety of PID controller tuning methods are proposed. These are broadly classified into three categories and these are
- Closed loop methods
  - Ziegler-Nichols method
  - Modified Ziegler-Nichols method
  - Tyreus - Luyben method
  - Damped oscillation method

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- Open loop methods
  - Cohen and Coon method
  - Fertik method
  - IMC method
  - Minimum error criteria (IAE, ISE, ITAE) method
- Soft computing methods
  - Fuzzy Logic
  - Artificial Intelligence
  - Genetic Algorithm
  - Evolutionary Programming

In Closed loop tuning methods the plant is operating in closed loop and controller tuning is performed during automatic state .In contrast the open loop techniques operate the plant in open loop and the controller tuning is done in manual state. In soft computing methods, tuning parameters are estimated based on the guiding principles i.e. uncertainty, tractability achievement approximation, robustness and minimum solution cost. In this paper the tuning methods considered for simulation are

Ziegler-Nichols method, Cohen and Coon method, Minimum error criteria (IAE, ISE, ITAE) method and Genetic Algorithm (GA) based tuning.

Ziegler-Nichols method: Ziegler-Nichols (ZN) tuning rule was the first tuning rule to provide a practical approach for PID controller tuning. Based on the rule, a PID controller is tuned by firstly setting it to the Proportional-only mode but varying the gain to make the process system in continuous oscillation (the edge of the stability).The corresponding gain is called as the ultimate gain *Ku* and the oscillation period is denoted as the ultimate period *Pu*.

A Simulink model for closed loop process with P-control is simulated to determine the above parameters. The ultimate gain *Ku* and the ultimate period *Pu* are also calculated analytically using Routh array. The key step of the Ziegler-Nichols tuning approach is to estimate the ultimate gain and period [9]. Then, the controller tuning parameters (P,I,D) are calculated from *Ku* and *Pu* using the Ziegler-Nichols tuning Table I.

TABLE I
ZIEGLER-NICHOLS TUNING

Controller	K_C	T_I	T_D
P	$K_u/2$		
PI	$K_u/2.2$	$P_u/1.2$	
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

Cohen and Coon method: In this method control action is removed and an open loop transient is introduced by a unit step change in the signal to the process. At the output of the measuring element the step response is recorded which is called as process reaction curve as shown in Figure 2.Then the dynamics of process is approximated by a first order plus transportation lag model, with following parameters

$T = 1.5(t_2 - t_1)$ (7)

$T_d = (t_2 - r_m)$ (8)

$K_p = \Delta Cs$ for unit step input (9)

Where

$t1$ = time at which $\Delta C = 0.283\ \Delta Cs$

$t2$ = time at which $\Delta C = 0.632\ \Delta Cs$

C = the plant output.

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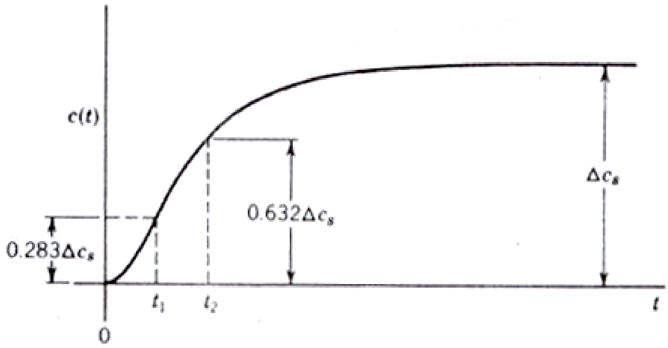

Fig.2 Typical process reaction curve

This technique that published by Dr C. L. Smith [10] gives a better approximation to process reaction curve by first order plus transportation lag process After estimation of three parameters of k_p , T and T_d, the tuning parameters can be obtained, using Cohen-Coon [11] relations given in Table II. These relations were derived empirically to provide closed loop response with a ¼ decay ratio. A Simulink model for open loop system is simulated for unit step input and k_p , T and T_d are determined from the open loop response.

TABLE II
COHEN-COON TUNING RULE

Controller	K_C	T_I	T_D
P	$T/ k_pT_d(1 + T_d/3T)$		
PI	$T/ k_pT_d(9/10 + T_d/12T)$	$T_d(30+3T_d/T)/ (9+20T_d/T)$	
PID	$T/ k_pT_d(4/3 + T_d/4T)$	$T_d(32+6T_d/T)/ (13+8T_d/T)$	$4T_d/ (11+2T_d/T)$

Minimum error criteria (IAE, ISE, ITAE) method: As mentioned before tuning for ¼ decay ratio often leads to oscillatory responses and also this criterion is developed by considering the closed loop response only at two points(the first two peaks). Another approach is to introduce controller design relation based on a performance index that considers the entire closed loop response. Some of the performance indices are

1) Integral of the absolute value of the error (IAE)

$$\mathbf{IAE}= \int |e(t)|\,dt \qquad (10)$$

2) Integral of the square value of the error (ISE)

$$\mathbf{ISE}= \int e^2(t)\,dt \qquad (11)$$

3) Integral of the time weighted absolute value of the error (ITAE)

$$\mathbf{IATE}= \int t\,|e(t)|\,dt \qquad (12)$$

where t is the time and e (t) is the error which is calculated as the difference between the set point and the output.

Procedure to determine Controller tuning parameters: The following steps are taken to design PID controllers using the minimum error criteria (ISE, IAE, and IATE).
i) The three tank process model including the controller algorithms in Simulink is developed
ii) A matlab m-file with an objective function that calculates the minimum error criteria is created.
iii) A function of matlab optimization toolbox is used to minimize the minimum error criteria.

On each evaluation of the objective function, the process model develop in the Simulink is executed and the specified performance index and the corresponding tuning parameters (P, I, D) are determined using Simpson’s 1/3 rule [12].

Genetic Algorithm (GA) based tuning: The genetic algorithm is an optimization technique that fulfills a parallel, stochastic, but directed search to determine the fittest population. The GA-PID controller consists of a conventional PID controller with its parameter optimized by genetic algorithm. By executing the following three steps Genetic algorithm breeds computer programs to solve optimization problems.

1) An initial population of compositions of the functions and terminals of the optimization problem is generated

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2) Perform the following sub steps iteratively on the population of programs until the criterion for the termination has been achieved:
a) Each program in the population is executed and fitness value using the fitness measure is applied.
b) A new population of programs is created by applying the following operations.
   Reproduction
   Crossover
   Mutation
3) The identified individual program is designated by result designation (e.g., the best-so far individual). This result may be a solution (or an approximate solution) to the problem. The specification of the designed GA technique is shown in Table III.

Figure 3 shows the flowchart of the parameter optimizing procedure using GA. For details of genetic operators and each block in the flowchart, one may consult literature [13][14][15].A matlab m-file is developed based on Genetic algorithm with the specifications given in Table III. Optimum values of controller tuning parameters with respect to time are estimated by executing the matlab file.

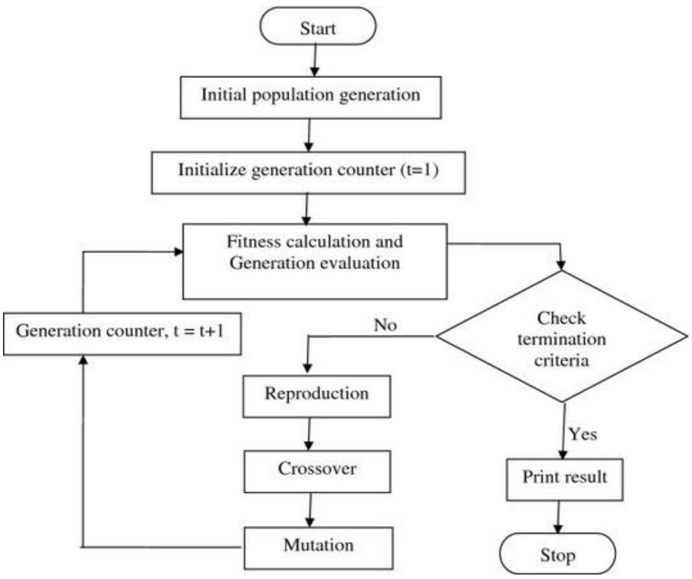

Fig.3 Flow chart for simulation of GA based PID controller

TABLE III
SPECIFICATIONS OF GA

Population Size	80
Crossover Rate	0.1
Mutation Rate	0.05
Chromosome Length	10
Precision of Variables	3
Generation Gap	1

IV. SIMULATION RESULTS

Figure 4 depicts the process model developed in Simulink to simulate the three tank process control system using trial and error method; the optimum tuning parameters of the controller in z-n and c-c methods are estimated from the simulation results of Simulink diagram. In minimum error criteria method(IAE,ISE,ISTE) optimum tuning parameters

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are estimated by declaring tuning parameters(P,I,D) of controller in Simulink as global variables and executing the matlab file which invokes a function fminseasrch from matlab optimization toolbox[16]. The controller tuning parameters estimated by Ziegler-Nichols, Cohen-Coon and minimum error criteria (IAE, ISE, IATE) methods are listed in table III. The GA based PID controller tuning parameters are estimated using matlab file and the obtained tuning parameters are shown in Figure 5.

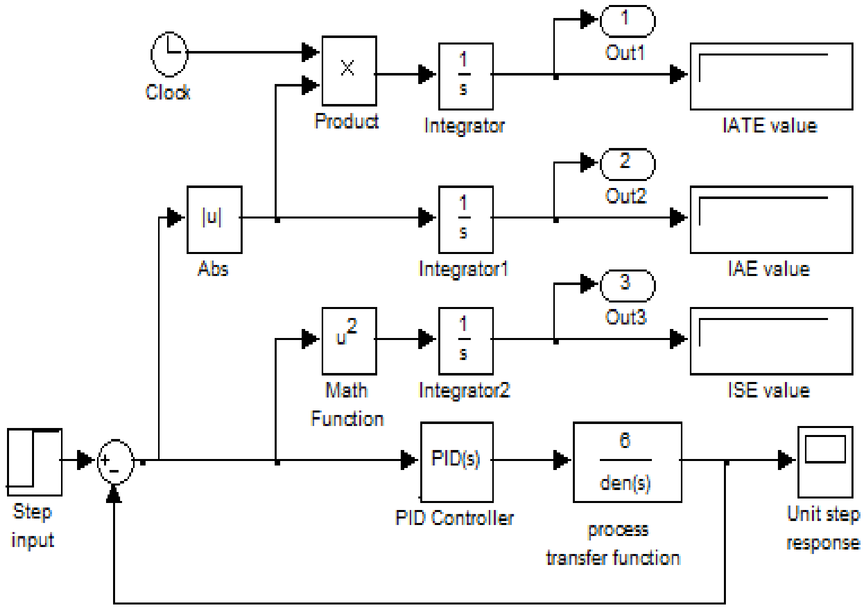

Fig.4 Simulink model of three tank process control system

TABLE III
OPTIMUM TUNING PARAMETER VALUES FOR VARIOUS TUNING METHODS

Tuning method	**Optimum values of PID controller tuning parameters**		
	P(Proportional gain)	**I(Integral gain)**	**D(Derivative gain)**
Ziegler-Nichols method	6.00	6.33	1.42
Cohen-Coon method	7.20	7.33	1.09
IAE method	12.13	6.41	7.96
ISE method	6.84	19.90	19.78
IATE method	12.13	6.41	7.96

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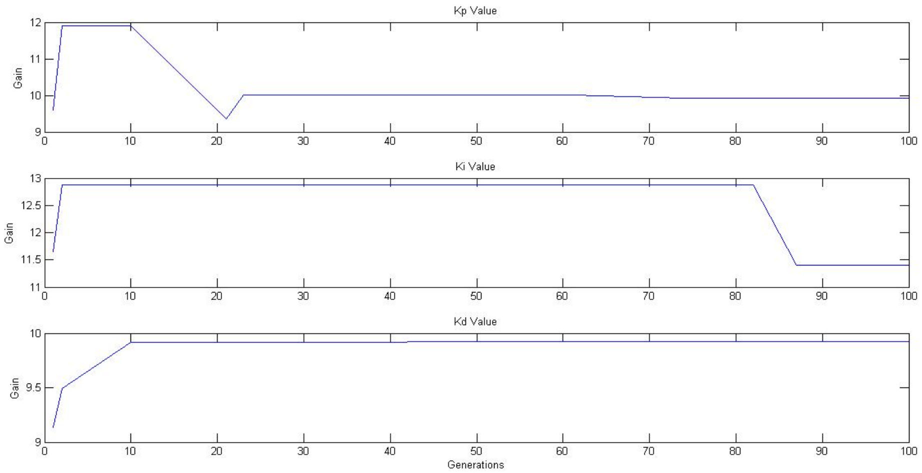

Fig.5 Optimum tuning parameters of PID controller using Genetic Algorithm

With these tuning parameters Comparison results obtained for P,PI and PID controllers by Ziegler –Nichols and Cohen –Coon methods for the three tank level processes for a unit step change in set point are shown in figures 6(a) and 6(b) respectively and the corresponding time domain specifications are listed in tables IV and V. In both tuning methods, PID controller gave better performance compared to P and PI controllers with reference to settling time, rise time, offset, ISE, IAE and IATE. Compared to Ziegler –Nichols and Cohen-Coon methods PID controller gave better performance in Ziegler-Nichols tuning method. Similarly with optimum tuning parameters the system responses for unit step input for remaining tuning methods are shown in figures 6(c) to 6(f). For comparison purpose the performance indices of three tank level process for unit step input by various PID tuning methods are listed in table VI. The simulation results indicate that unit step response presents better performance using GA based PID tuning method compared to other tuning methods.GA based tuning method gave minimum peak overshoot, minimum settling time and less integral square error.

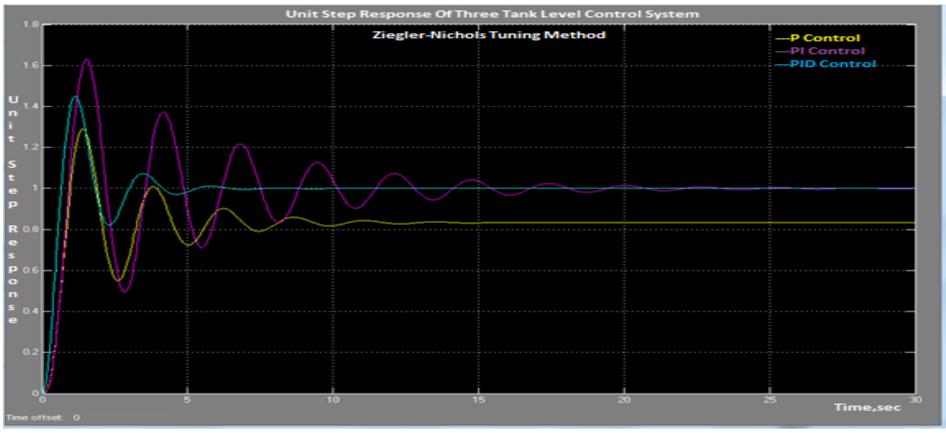

Fig.6(a) Ziegler-Nicholas method

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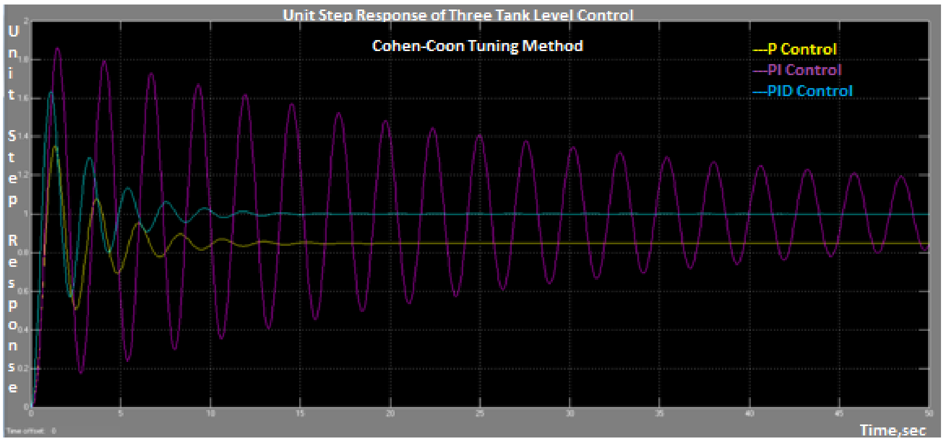

Fig.6(b) Cohen and Coon method

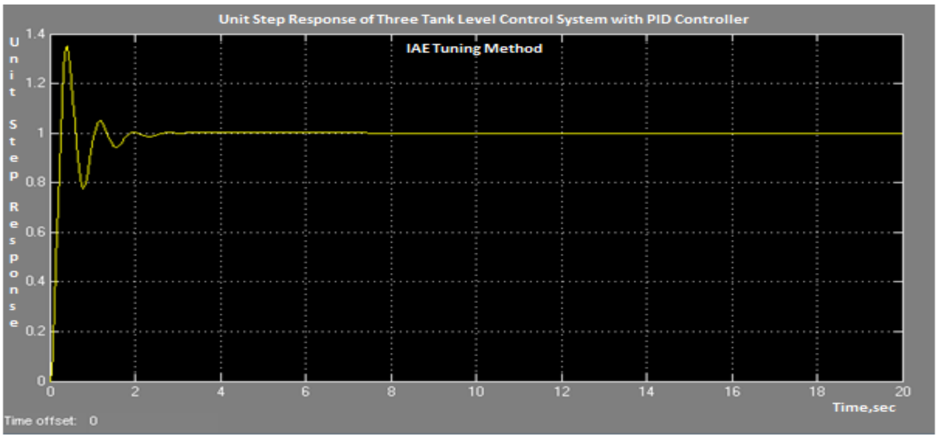

Fig.6(c) IAE method

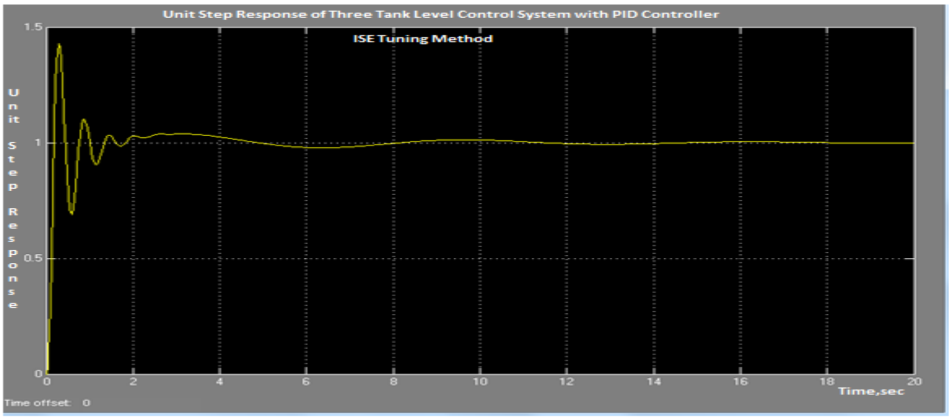

Fig.6(d) ISE method

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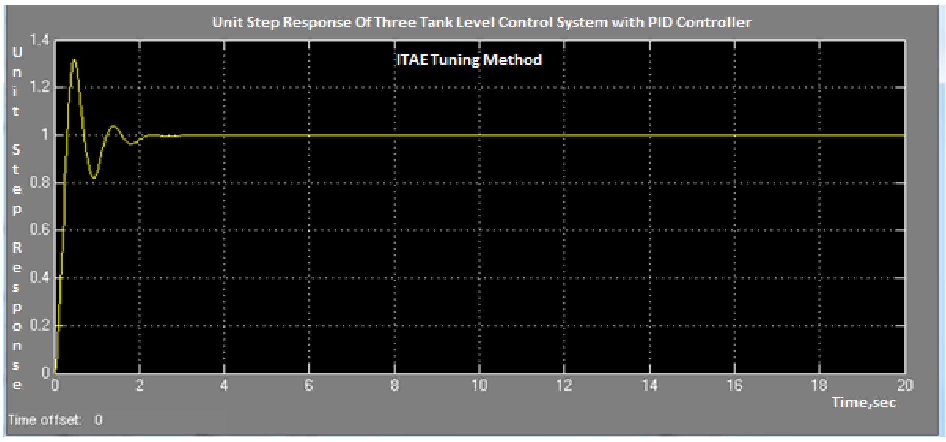

Fig.6(e) IATE method

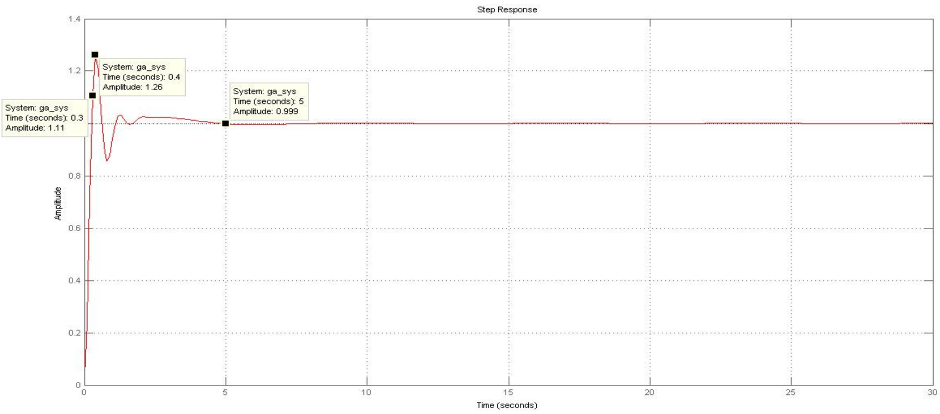

Fig.6(f) GA based PID controller

Fig.6 Unit step response of three tank process control system for various tuning methods

TABLE IV
COMPARISON OF TIME DOMAIN SPECIFICATIONS OF THREE TANK LEVEL PROCESS USING ZIEGLER-NICHOLS METHOD

Time domain specification	**P-Control (P = 5)**	**PI-Control (P= 4.50; I = 2.85)**	**PID-Control (P= 6.00; I = 6.33;D=1.42)**
Rise Time,sec	0.955	0.918	0.655
Peak Time,sec	1.270	1.530	1.130
Settling Time,sec	19.00	32.50	11.10
Peak Overshoot	1.263	1.630	1.450
Offset	0.166	0.000	0.000
ITAE	208.8	13.45	1.167
IAE	8.934	2.887	0.939
ISE	1.995	1.144	0.439

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TABLE V
COMPARISON OF TIME DOMAIN SPECIFICATIONS OF THREE TANK LEVEL PROCESS USING COHEN –COON METHOD

Time domain specification	**P-Control (P = 5.56)**	**PI-Control (P= 4.79; I = 4.66)**	**PID-Control (P= 7.20; I = 7.33; D=1.09)**
Rise Time,sec	0.910	0.850	0.625
Peak Time,sec	1.400	1.450	1.100
Settling Time,sec	23.00	200.0	17.50
Peak Overshoot	1.314	1.860	1.635
Offset	0.150	0.000	0.000
ITAE	191.2	271.1	4.663
IAE	8.334	14.57	1.736
ISE	1.818	6.229	0.706

TABLE VI
COMPARISON OF PERFORMANCE INDICES OF THREE TANK LEVEL PROCESS USING PID TUNING METHODS

Time domain Specification	**Ziegler-Nichols (Z-N) method**	**Cohen-coon (C-C) method**	**Minimum error criteria method**			**Genetic Algorithm (GA)**
			ITAE	**IAE**	**ISE**	
Rise Time,sec	0.655	0.625	0.300	2.650	0.180	0.300
Peak Time,sec	1.130	1.100	0.460	4.280	0.282	0.400
Settling Time,sec	11.10	17.50	7.500	19.59	20.50	5.000
Peak Overshoot	1.450	1.635	1.316	1.350	1.428	1.260
Offset	0.000	0.000	0.000	0.000	0.000	0.000
ITAE	1.167	4.663	0.178	0.217	1.533	3.110
IAE	0.939	1.736	0.345	0.337	0.476	1.700
ISE	0.439	0.706	0.165	0.151	0.134	0.050

V.CONCLUSION

Optimum tuning parameters of PID controller are estimated by six tuning methods (Z-N method, C-C method, ISE, IAE, IATE and GA based PID method) for three tank level process for using Matlab/Simulink. Simulated results show that GA based PID controller results in quick response with smaller peak overshoot and integral square error. Moreover, this method has good ability to adapt to the tuning parameters for changes in process dynamics. To summarize, the GA based PID controller has been proved to be an efficient method in the three tank level control process. This method can be also used in a variety of non linear process control systems with large transportation lag processes. This paper will be extend in future to the evolutionary algorithms to determine optimum PID tuning parameters.

REFERENCES

[1] Graebe S.F., Goodwin G.C., “Control Design and Implementation in Continuous Steel Casting”, IEEE Control Systems, August 1995, pp.64-71.
[2] Cheung Tak-Fal, LuybenW.L.,”Liquid Level Control in Single Tanks and Cascade of Tanks with Proportional-only and Proportional – Integral Feedback controllers”,Ind.Eng.Chem.Fundamentals,vol.18, No.1,1979,pp. 15-2.
[3] Astrom, K., T. Hagglund, “PID Controllers; Theory, Design and Tuning”, Instrument Society of America, Research Triangle Park, 1995.
[4] S.N.Sivanandam, S.N.Deepa, “Introduction to Genetic Algorithms”, Springer Publications Co., 2010.
[5] J.G.Ziegler and N.B.Nichols, “Optimum settings for automatic controller”, ASME Trans, Vol64, 1942, pp.759-768.
[6] W.K.Ho.C.C.Hang. and J.H.Zhou,”performance and gain and phase margins of well-known PI tuning formulas”, IEEE Transaction. Control systemsTechnology, 1995.
[7] D. E. Goldberg, “Genetic Algorithms in Search, Optimization, and Machine Learning”, Addison-Wesley Publishing Co., Inc., 1989.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 1, January 2014

[8] A.H.Jones and M.L.Tatnall,"Online frequency domain Identification for Genetic tuning of PI Controllers", Proceedings of ICSE, Coventry, 1994.
[9] J. G. Ziegler and N. B. Nichols, "Optimum settings for Automatic Controllers", ASME Transactions, vol. 64, pp. 759–768, 1942.
[10] Smith, C.A., A.B. Copripio;"Principles and Practice of Automatic Process Control", John Wiley & Sons, 1985.
[11] Seborg, D.E., T.F. Edgar, D.A.Mellichamp; "Process Dynamics and Control", John Wiley & sons, 1989.
[12] S.C.Chapra and R.P.Canale., "Numerical Methods for Engineers", McGraw-Hill International Edition, New York, 1998.
[13] L.Hao, C. L. Ma and F. Li, "Study of Adaptive PID Controller Based on Single Neuron and Genetic Optimization", The 8th International Conference on Electronic Measurement and Instruments ICEMI, Vol. 1, 2007, pp. 240-243.
[14] R. Koza, F. H. Bennett, A. David and K. Martin, "A Genetic Programming III: Darwinian Invention and Problem Solving", Morgan Kaufmann, San Francisco, 1999.
[15] C. R. Reeves, "Using Genetic Algorithms with Small Populations", Proceedings of the 5th International Con-ference on Genetic Algorithms, 1993.
[16] F.G.Martins, "Tuning PID controllers using the ITAE criterion", International Journal Engineering Edition, vol.21, No.3, 2005