Level Control using a Genetic Algorithms Based PID Control Design

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ABSTRACT

The PID controller is still one of the most dominant control strategies which are widely applied for industrial process control because of their simplicity and robustness. However, the increasing complexity of the modern control systems has emphasized the idea of applying more efficient computing approaches such as neural networks and genetic algorithms in order to solve complicated design problems that may not be handled by conventional PID controllers. An extension to previous work [1], in this paper the PID based Genetic Algorithms controller is applied to interacting double-tank system [2]. In addition this work investigates the effect of different Performance indices (MSE, ITAE, ISE and IAE) that are used for optimizing the setting of PID controller gain values. Also this article compares the PID based Genetic Algorithms controller with the traditional Ziegler Nichols tuning method to demonstrate the effectiveness of these performance indices in the closed-loop responses in both time domain and frequency domain.

Keywords: PID controller, MES, ITAE, ISE, IAE, Genetic Algorithms, interacting double-tank system.

1. Introduction

It is well-known fact that Proportional-Integral-Derivative (PID) controllers are the most widely used for industrial control. The popularity of these controllers is due to the robustness of these controllers to control a wide range of processes and the simplicity of their structures [3]. Therefore, a great deal of attention has been given to PID controllers and their applications [3, 4, and 5]. Many conventional PID tuning methods were well- established in both academia and industry. Some of these tuning methods are based on mathematical criteria (i.e. Cohen –Coon method), Trial and Error Methods and Experimental Method (i.e. the Ziegler-Nichols method) [6, 7]. However, these tuning methods are tedious and time consuming and the resulting PID controllers is still suffer from considerable limitations in that they need to be retuned in the situation where the system to be controlled is subjected to some kind of disturbances or process operating points change is happened. Hence, such these type of classical tuning methods is not sufficient to obtain satisfactory responses [3]. For this reason a more optimal tuning approach is required. One way to achieve this objective is to use a powerful and broadly applicable stochastic global optimization method such as Genetic Algorithms as effective and efficient tuning tool [8, 9]. Many researches has been conducted to use the GAs in tuning the classical PID [10, 11 and 12]. However, the performance of GAs depends on the choice of the employed objective functions, for instance the mean of the squared error (MSE), the integral of the time weighted absolute value of error (ITAE), the Integral of the square value of error (ISE) and the integral of the absolute value of error (IAE) [13, 14]. In this note, this article focuses on the effect of using different Performance indices (MSE, ITAE, ISE and IAE) applied to an interacting double-tank system. This paper is organized as follows: the system model of the interacting double-tank system is formulated in section 2. A brief focuses on GA based PID Controller tuning methods and how it can be applied to an interacting double-tank process is presented in section 3. Section 4 reviews the concept of the Genetic Algorithms. The simulation using various GA based PID indices was carried out to demonstrate the performance of the closed-loop system is presented in section 5. The concluded remarks and recommendations for future work are given in section 6.

2. Modeling of a Double-tank System

Level control is one of the most accruing problem in process control. The main objective of the Genetic Algorithm based PID controller is to track the set-point with satisfactory process response. In this paper the two interacting liquid tanks in the Fig.1 [2] is considered. The process is consisting of two tanks (tank1 and tank2).

The q_{in} (cm^3/min) is the volumetric input flow into tank1, the volumetric flow rate from tank1 to tank2 is q_1 (cm^3/min), and q_o (cm^3/min) is the volumetric flow rate from tank2. The height of the liquid level in tank1 is h_1 (cm) and in tank2 is h_2 (cm). Cross-sectional area of both tanks are the same, denotes the area of tank1 is A_1 (cm^2) and tank2 area is A_2 (cm^2). R_1 is the resistance caused by tank1 outlet valve and R_2 is the resistance of tank2 outlet flow valve.

The main objective of this section is to find the process transfer function: $\frac{h_2(s)}{q_{in}(s)}$

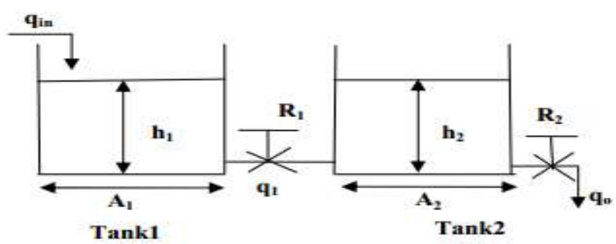

Figure.1 the two interacting liquid tanks diagram

In order to derive the mathematical dynamic model of the two interacting liquid tanks process showed in Fig. 1, the following assumptions are made [2]:

For liquid tank-1:

$$A_1 \frac{dh_1}{dt} = q_{in} - q_1 \qquad (1)$$

If a linear resistance to flow is assumed, we get:

$$q_1 = \frac{h_1 - h_2}{R_1} \qquad (2)$$

$$A_1 \frac{dh_1}{dt} = q_{in} - \frac{h_1 + h_2}{R_1} \qquad (3)$$

$$R_1 A_1 \frac{dh_1}{dt} = R_1 q_{in} - h_1 + h_2 \qquad (4)$$

Taking Laplace transform to equation (4) we obtain

$$h_1(s)(R_1 A_1 s + 1) - h_2(s) = R_1 q_{in}(s) \qquad (5)$$

For liquid tank-2

$$A_2\frac{dh_2}{dt} = q_1 - q_0 \quad (6)$$

If linear resistance to flow is assumed, then we have:

$$q_0 = \frac{h_2}{R_2} \quad (7)$$

$$A_2\frac{dh_2}{dt} = \frac{h_1+h_2}{R_1} - \frac{h_2}{R_2} \quad (8)$$

$$R_2A_2\frac{dh_2}{dt} + h_2 + \frac{R_2}{R_1}h_2 = \frac{R_2}{R_1}h_1 \quad (9)$$

Taking Laplace transform to equation (9) we obtain:

$$h_2(s)\left(R_2A_2s + \frac{R_2}{R_1} + 1\right) = \frac{R_2}{R_1}h_1(s) \quad (10)$$

Using equations (5) and (10) the system transfer function is obtained as:

$$\frac{h_2(s)}{q_{in}(s)} = \frac{R_2}{A_1R_1A_2R_2s^2+s(A_1R_1+A_2R_1+A_2R_2)+1} \quad (11)$$

Using the values of the Parameters shown in table1 we derived the system final transfer function as follows:

$$\frac{h_2(s)}{q_{in}(s)} = \frac{0.01}{6.25S^2+7.5S+1} \quad (12)$$

Table 1: *Parameters for the two interacting liquid tank system*

Parameters	**Value**	**Unit**
A1	250	cm^2
A2	250	cm^2
R1	0.01	cm^2/sec
R2	0.01	cm^2/sec
H1	30	cm
H2	15	cm

3. PID Controller Tuning Methods

Many traditional PID controller tuning techniques are introduced in industrial control. The most commonly used tuning method is a Ziegler-Nichols tuning approach of [6]. This technique depends on experiments executed in advance on the process to be controlled. However, it is time consuming and a prior knowledge of the process model is required in order to provide accurate values of PID controller parameters to avoid a poor closed-loop response [15, 16]. On the other hand, the estimation of tuning parameters in the artificial intelligent techniques is based on the guiding principles such as, reference point tracking, stability, minimizing the solution of desired cost function and achieving robust performance. Genetic algorithms which are used to design a PID controller based on a specified performance index (objective function). Therefore, in this work the effects of the most common approaches of performance indices, such as the mean of the squared error (MSE), the integral of the time weighted absolute value of error (ITAE), the Integral of the square value of error (ISE) and the integral of the absolute value of error (IAE) are considered, These performance indices which influence the closed-loop performance can usually be evaluated analytically in the time domain and the frequency domain [15, 16]. These objective functions which are mentioned above can be expressed as follows:

1) The mean of the squared error (MSE) :

$$MSE = \int_0^t e(t)dt$$

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

$$ITAE = \int_0^t t|e(t)|\,dt$$

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

$$ISE = \int_0^t e^2\,(t)dt$$

4) Integral of the absolute value of the error (IAE):

$$IAE = \int_0^t |r(t) - y(t)dt| = \int_0^t |e(t)|\,dt$$

Where, t is the time the actuating signal that computed as the difference between the reference signals and $e(t)$is the output.

4. Genetic Algorithm overview

Genetic Algorithms is a powerful and broadly applicable stochastic global optimization method based on the mechanisms of natural evaluation and the survival of the best chromosome, which is inspired by Darwinian Theory. It has been recognized as an effective and efficient technique to solve optimization problems compared with other optimization techniques. The Genetic Algorithms Architecture is represented in Fig.2 it can be seen from Fig.2 that Genetic Algorithms starts with an initial population containing a number of encoded strings known as chromosomes; each string represents a solution of the problem. Crossover operator is used on these strings to obtain possible solutions, which inherit the good and bad properties of their parents' solutions. Each solution has a fitness value. The solutions that are having higher fitness value are the most likely survived for the next generation. Mutation operator applied to produce new characteristics, which are not found in the present solution. Over successive generations, the population "evolves" toward the optimum solution to the problem [8, 9].

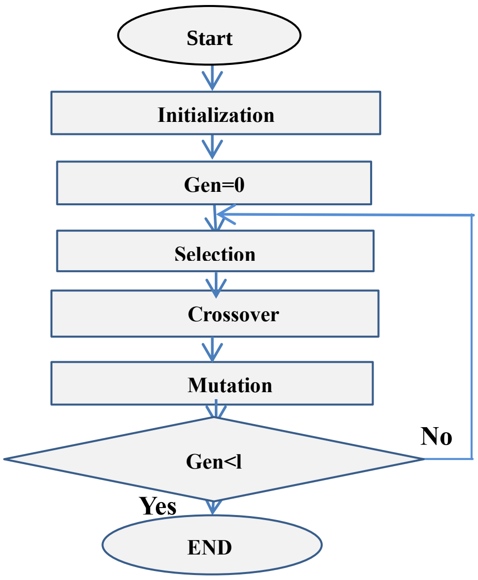

Fig.2: Genetic Algorithms Architecture.

5. Simulation Results

In this section the double-tank level control system presented by equation (12) is controlled by Classical Ziegler-Nichols tuned PID controller and GA based PID Controller tuning method. This section is arranged to be consisting of three subsections 5.1, 5.2 and 5.3. In subsection (5.1) the classical Z-N tuned PID controller is used, whereas GA based PID Controller tuning method using various performance indices outlined in subsection (5.2). In subsection (5.3) the simulation results are discussed. In all simulation experiments' results, we assume that the reference signal is a unit step signal.

5.1 Classical Ziegler-Nichols Tuned PID Controller

In this part the well-known traditional Ziegler-Nichols controller is used. The PID gain values using this method are given in table 2. The step response of the closed-loop system is shown in Fig.3a and the Bode plot response are presented in Fig.3b.

Table 2*: Controller gain values*

Gain Coefficients	K_d	K_p	K_i
Gain values	50	600	100

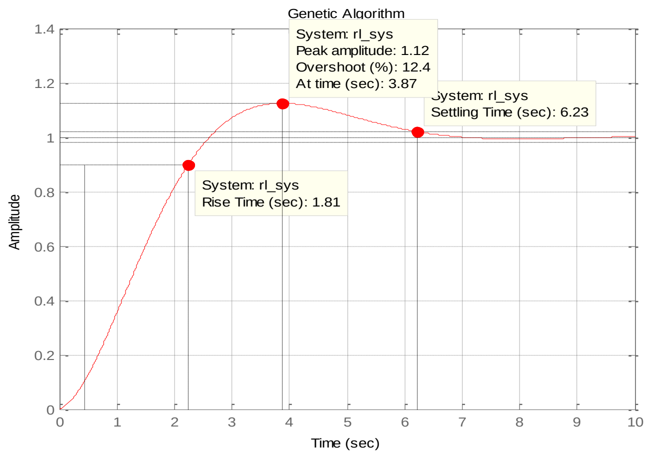

Fig.3a: Response of the system with classically tuned PID controller.

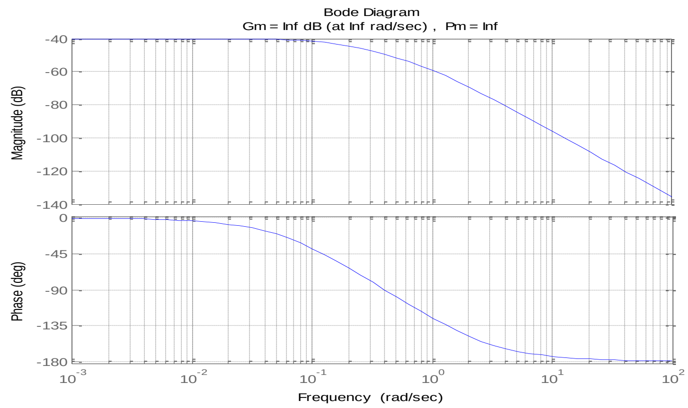

Fig.3b: Gain margin and phase margin response using Z-N tuned PID controller.

5.2 GA based PID Controller tuning method using various performance indices.

In this subsection, in order to investigate the effect of the various performance indices on the closed-loop system responses four simulation experiments were carried out considering the performance indices and the specifications of the designed GAs technique shown in table 3.

Table 3: *Specifications of GA*

GA property	Value / Method
Function of fitness	MSE, ITAE, ISE and IAE
Population size	80
Selection method	Geometric Selection
Mutation rate	Uniform Mutation
Mutation probability	0.01
Crossover rate	Arithmetic
N. of crossover points	0.05

5.2.1 Experiment 1: GA Based PID Controller Using MSE Method

Figure.4a shows the response of GA based PID controller using MSE method. The obtained values of the GA based PID controller parameters, Kd = 9995.06249 Kp = 9974.72661 . and Ki = 1641.5990 , are shown in Fig.4b. Whereas, the frequency domain performance criteria gain margin (GM = ∞), phase margin (PM = 178), are illustrated in Fig.4c.

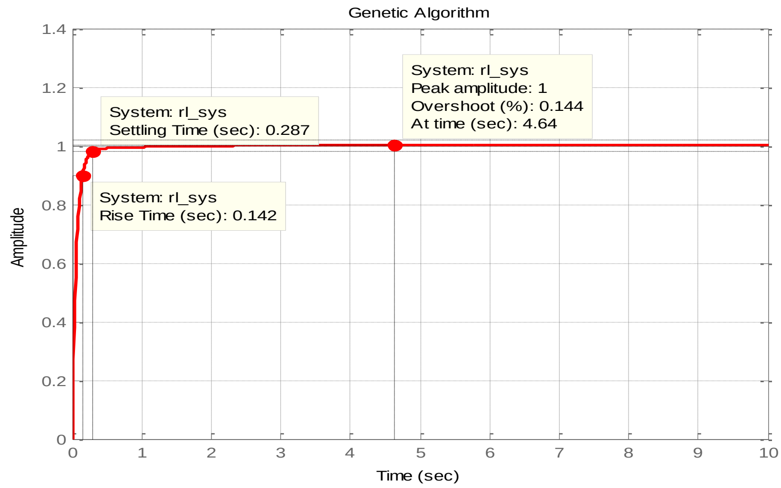

Fig.4a: GA based PID using MSE method response

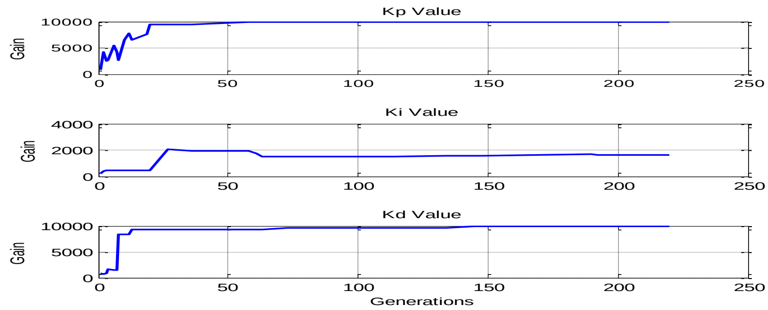

Fig.4b: Genetic Algorithm values

$$Kd = 9995.06249, Kp = 9974.72661 \quad Ki = 1641.5990$$

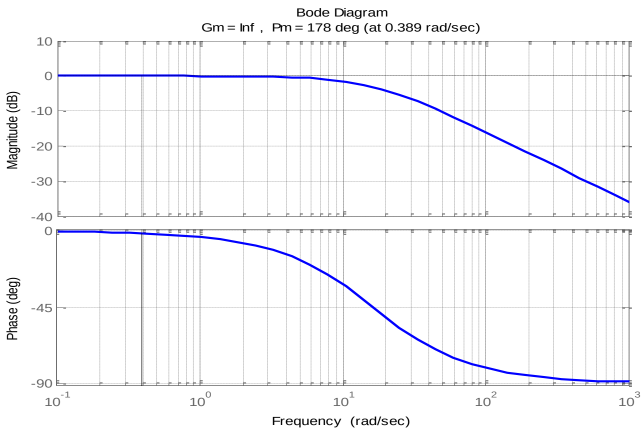

Fig.4c: Gain margin and phase margin response

5.2.2 Experiment 2: GA Based PID Controller Using ITAE Method

The GA based PID controller response using ITAE performance index is presented in Fig. 5a and the obtained controller parameters of GA based PID, $K_d = 7625.159$, $K_p = 9135.08271$ and $K_i =$

1225.3986, which are presented in Fig.5b. The Bode plot including the values of GM and PM are shown in Fig.5c.

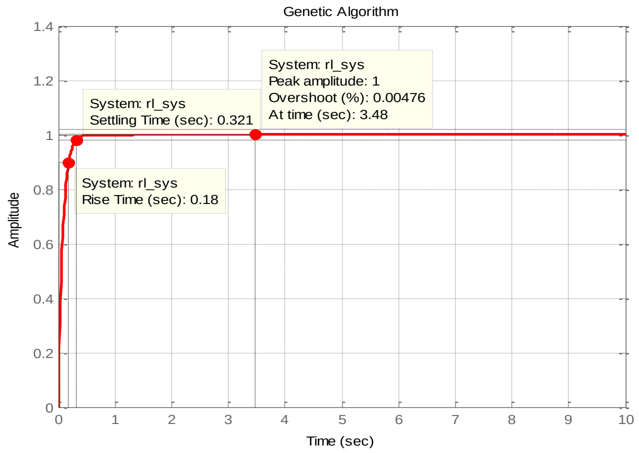

Fig.5a: Response of GA based PID using ITAE

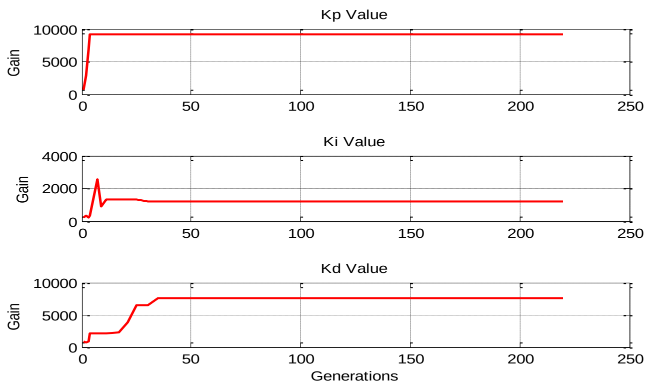

Fig.5b: Genetic Algorithm values

$$Kd = 7625.64159 \quad Kp = 9135.08271 \quad Ki = 1225.3986$$

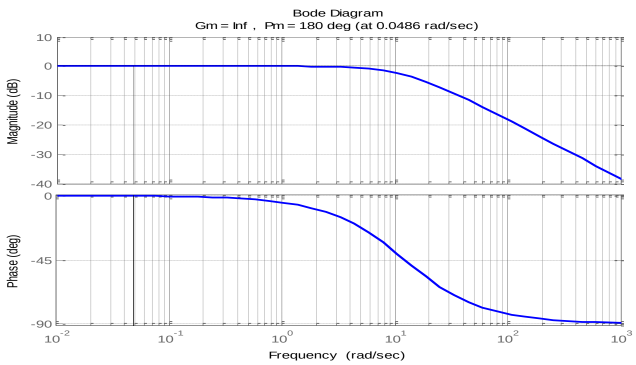

Fig.5c: Gain margin and frequency margin response

5.2.3 Experiment 3: GA Based PID Controller Using ISE Method

The GA based PID controller using ISE method response is shown in Fig.6a, whereas the GA based PID controller parameters ($K_d 9774.13865 =$, $K_p = 9981.43889$ and $K_i = 1684.0275$) are shown in Fig.6b. The gain margin ($GM = \infty$) and phase margin ($PM = 178$), are shown in Fig.6c.

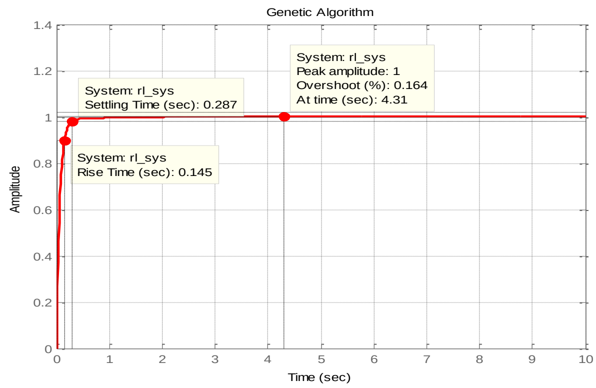

Fig.6a: Response of GA based PID using ISE

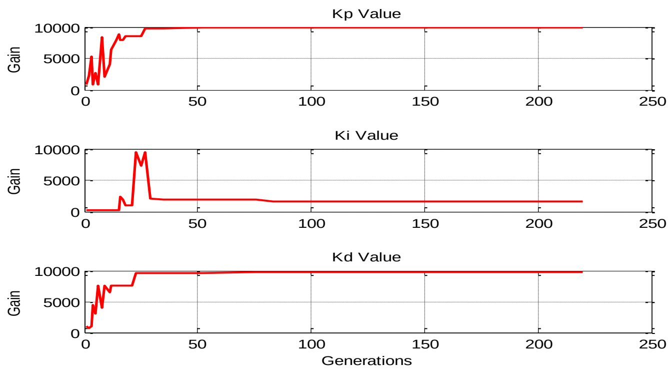

Fig.6b: Genetic Algorithm values

$$Kd = 9774.13865 \; Kp = 9981.43889 \; Ki = 1684.0275$$

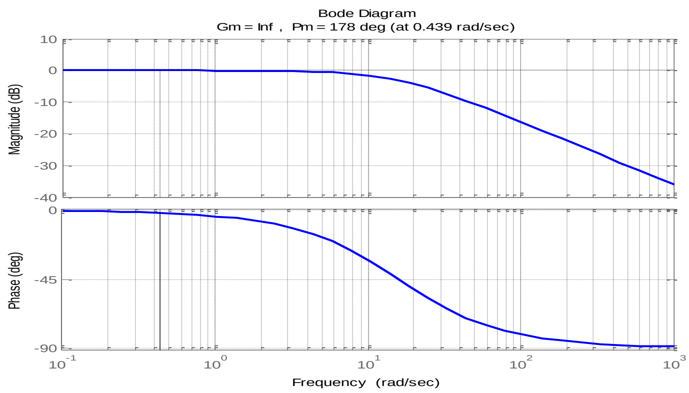

Fig.6c: Gain margin and frequency margin response

5.2.4 Experiment 4: GA Based PID Controller Using IAE Method

Figure.7a shows the response of GA based PID controller using IAE method. The obtained values of the GA based PID controller parameters, $K_d = 9511.31546$, $K_p = 7758.98722$ and $K_i = 6868.5717$, are shown in Fig.7b. Whereas, Fig.7c shows the frequency domain performance criteria gain margin ($GM = \infty$), phase margin ($PM = 173$), are illustrated in Fig.7c.

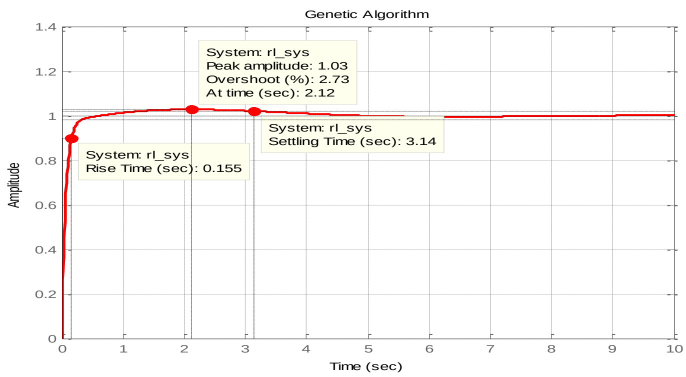

Fig.7a: Response of GA based PID using IAE

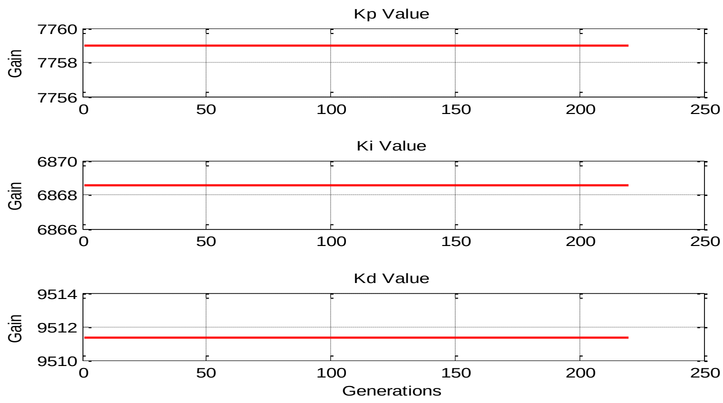

Fig.7b: Genetic Algorithm values

$$Kd = 9511.31546 \; Kp = 7758.98722 \; Ki = 6868.5717$$

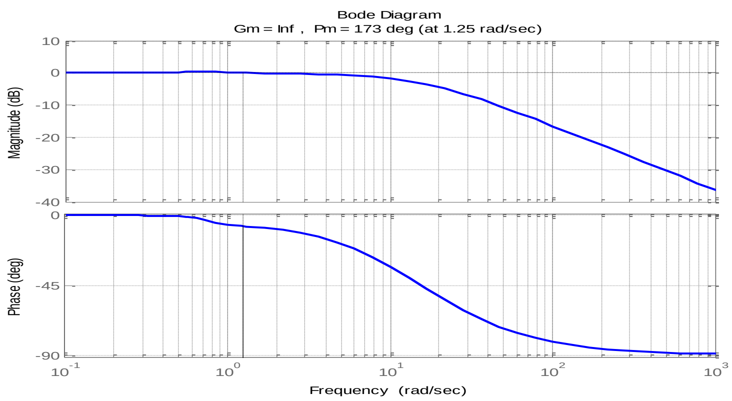

Fig.7c: Gain margin and frequency margin response

5.3 Simulation Results Analysis

In this work, five simulation experiments including Ziegler –Nichols tuning technique have been performed using Matlab environment for both the classical PID controller tuned by Ziegler –Nichols tuning method and the GA based PID controller in order to evaluate the performance of the various objective functions (MSE, ITAE, ISE and IAE) with application to the interacting double-tank process. For the reason of readability, all simulation results are summarized in table 4.

Table 4: *PID controller tuning parameters' values obtained from five tuning methods.*

Tuning method	Optimized PID controller tuning parameters' values							
	K_d	K_p	K_i	T_s	T_r	OP %	PM	GM deg.
Z and N	12	500	100	6.23	1.81	12.4	∞	∞
MSE	9995.06249	9974.72661	1641.5990	0.287	0.142	0.144	∞	178
ITAE	7625.64159	9135.08271	1225.3986	0.321	0.18	0.00476	∞	180
ISE	9774.13865	9981.43889	1684.0275	0.287	0.147	0.64	∞	178
IAE	9511.31546	7758.98722	6868.5717	3.14	0.155	2.73	∞	173

From table 4, it is clear that the genetic algorithms based PID controller with various performance criteria give quick responses with smaller peak overshoots compared to Ziegler –Nichols tuning method. Also it is obvious that all frequency responses (phase margin and gain margin) values for all controllers are almost identical. However, it obvious from table 4 that using ITAE performance index yields the lowest overshoot percentage, whereas, the lowest rise time value is achieved when (MSE) is used. The lowest settling time is obtained, in the case where (IAE and MSE) performance indices are employed.

6. Conclusions and Future Work

As extension to the previous work done by the authors [1], the main objective of this article is to really assess the influence of the performance indices (MSE, ITAE, ISE and IAE) on the closed-loop responses for different process namely a double-tank level control system. In addition these simulations are also compared with the classically tuned Ziegler –Nichols technique. From the simulation results which are summarized in table (4), it can clearly be seen that the GA based PID with multi objective indices (MSE, ITAE, ISE and IAE) give better time domain performance criteria (Rise time, settling time and the percentage overshoot) than classically Z–N tuned PID controller. The GA based PID experimental results are showed that the lowest rise time was obtained when (MSE) is used, whereas, the lowest settling time value were obtained when (MSE and ISE) performance indices are used. The best overshoot percentage is maintained when (ITAE) is selected.

These results are different comparing with those are presented in the previous paper [1]. Therefore, it can be concluded that the selection of suitable performance criteria depends on process to be controlled. Further work can be done to modify an adaptive supervisory mechanism to automatically select on-line the best objective function using additional soft computing algorithm or statistical method such as Fuzzy Logic [17] or Stochastic Leaning Automata [18, 19].

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