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TUNING AND DESIGN OPTIMIZATION OF PID CONTROLLER FOR A PLANT

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ABSTRACT

The principal objective of this project work is to minimize and optimize the tuning and design algorithm for a PID controller without compromising with system parameters for example settling time, stability, and frequency instability. There are number of design techniques exist for a stable PID controller. Every design techniques have their own merits and demerits. The most promising and challenging problem is to find out the appropriate value of k_p, k_i and k_d for a higher order systems [1]. The presented work considers genetic algorithm for finding the solution and improve the technique to optimize the tuning of a PID controller for a plant. It further extended to use in design and optimization systems used PID controllers. Presented work ease the complexity of PID tuning and determines k_p, $k_{i,}$ k_d for any given transfer function of any order without going into detailed analysis and synthesis of the system, without compromising on system performance. All the analysis has done in MATLAB. The script and model windows are used for testing and simulations. The most popular methods of tuning of PID controllers "Ziegler- Nichols-Method (ZNM), Cohen-Coon-Method (CCM), Genetic-Algorithm-Method (GAM)" are also tested for the plant and current work found more satisfying with results.

Keywords: PID, FOPDT, ZNM, CCM, PGM, GAM, ITAE

1. INTRODUCTION

The tuning of PID controller is first reported by J.G. Ziegler and N.B. Nichols in 1942 and 1943 respectively [2]. They proposed how to get the optimal value of PID-parameters for open loop transfer function and closed loop transfer function. Afterwards, number of control instruments designed for gas/liquid/temperature/ pressure control. Since then there were continuous and from basic to complex developments have been observed. About 90% of the industries use the PID controller for their process control [4]. Thus, for example, a first order system with PID controller produces a third order characteristics equation; a second order will produce fourth order and so on. Finding a proper solution of these deferential equations becomes tedious job and hence the genetic algorithm plays an important role of calculating the proper solution in less time and provides a way for auto tuning of the system parameters. The proposed study was to compare the performance parameters of said design technique and an improved tuning algorithm for PID controllers for a generic plant. The algorithm takes it one step ahead and minimizes the time of computing while there is no compromise on response of the system. Even in some cases it provides better response than the conventional GA used. The results found are satisfying and consistent.

2. BACKGROUND

2.1 *PID Controller*

PID controller stands for Proportional Integral and Derivative controller used collectively to optimize the performance of a plant. In proportional (P) controller, output signal is proportional error signal, in integral (I) controller; it is proportional to the integration of error signal while in derivative (D) controller it is proportional to the derivative of the error signal. Proportional-Derivative (PD) controller controls transient response, proportional-integral (PI) controller minimizes the steady state error while PID controller includes three separate constant parameters vis. k_p, k_i and k_d. By tuning these constants of PID controller, the optimum response can be achieved. The PID controller is compared based on its settling time, overshoot, rise time, steady state error signal.

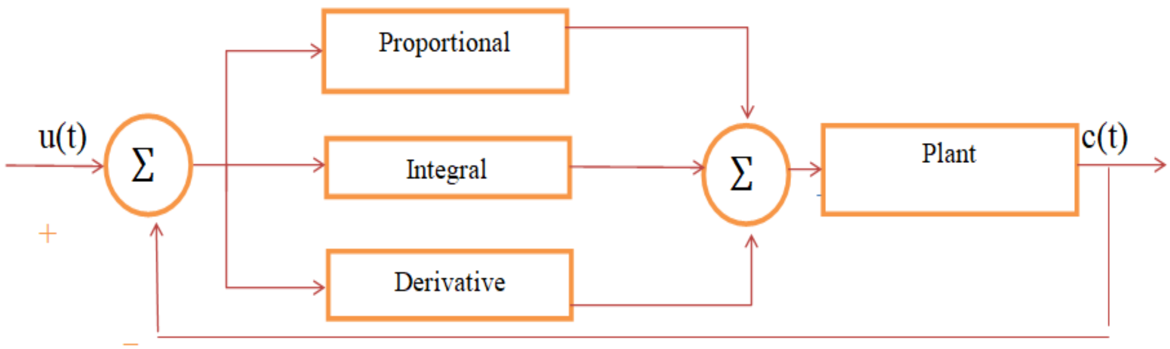

Figure 1: PID Controller

The transfer function of the PID controller G_{pid} can be expressed as

$$g(t)_{pid} = k_p e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dx} \text{.... (1)}$$

$$G_{PID}(S) = \frac{k_d S^2 + k_p S + k_p}{S} \text{.................... (2)}$$

If the transfer function of a plant is $G_P(S)$ then transfer function of the system is

$$G_{sys,\ O}(S) = G_{PID}(S)\ X\ G_P(S) \text{......... (3)}$$

$$G_{sys,\ C}(S) = \frac{G_{sys,\ O}(S)}{(1 + G_{sys,\ O}(S))} \text{.............. (4)}$$

$$C(S) = G_{sys,\ C}(S)\ X\ U(S) \text{.............. (5)}$$

Finding the solution for $\frac{C(S)}{S}$ provides the step response of the system with PID controller. Where $e(t) =$ Error signal in time domain

$g(t)_{pid}$ = Transfer function of PID controller in time domain

$G_{PID}(S)$ = Transfer function of PID controller in S domain

$G_P(S)$ = Transfer function of a plant in S domain

$G_{sys,\ O}(S)$ = Transfer function of open loop system with PID controller in S domain

$G_{sys,\ C}(S)$ = Transfer function of close loop system with PID controller in S domain

$C(S)$ = Output in S domain

$U(S)$ = Input in S domain

$k_p, k_i, and\ k_d$ = Gain constants

2.1 *Ziegler-Nichols*

Using inverse transform technique the formula derived for

$$k_{p,PID} = \left(1.35 * \left(1 + \frac{0.18*t}{(1-t)}\right)\right) * \frac{1}{a}; \text{....... (6)}$$

$$k_{i,PID} = \frac{L*(2.5-2*t)}{(1-0.39*t)};\ldots\ldots \quad (7)$$

$$k_{d,PID} = \frac{(0.37-0.37*t)}{(1-0.81*t)} \ldots\ldots \quad (8)$$

The technique used the relation $k_d = {k_i}/{n}$. It reduces the higher order system into lower order system and reduces the complexity of the system.

2.1 *Genetic Algorithm*

GA is a formula based optimization technique which finds the solution through natural selection of probable roots. The basic goal of GA is to optimize the possible solutions known as fitness function. It is also known as a Chromosome set. A chromosome also represents a probable solution. Most of the work reported based on GA, which directly apply it on real parameters. "Decimal-type GA's for computer-based numerical simulation lead to high computational efficiency, smaller computer requirements with no reduction of precision and greater freedom in selecting genetic operator.

GA has been successfully implemented in the area of industrial electronics, chemical, biomedical, aviation & control, mining, electrical, domestic appliances, mostly in computational field. For instance, parameter and system identification, control robotics, pattern recognition, planning and scheduling" [8][9]. The flow chart of genetic algorithm is shown in figure below [10].

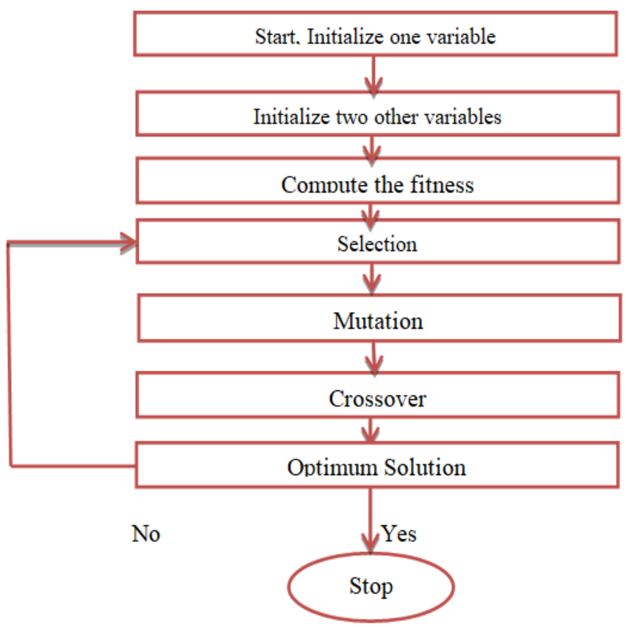

Figure 2: Flow chart of GA tuning of PID controller

2.1 *Improved GA*

It is widely known the complexity of search algorithm of GA method for tuning of a PID controller. For example, if as small as 100 iterations, 5 population and 4 chromosomes are taken then it will result into $(5 \times 2 \times 100 = 2000)$ times computation of parameters. If the same is targeted on computational processor it would require 2000 times of the $No.of\ instruction\ cycle \times T\_State$ required to compute a single fitness function.

There is some extra computation time required to get the optimum value of the solution. If, instead of computing for all the three proportional, integral and derivative gain constants, one of them is kept fixed then the number of computational instruction decreased significantly at least 2000 times of an instruction without compromising with the system stability and accuracy. It will further improve the scope of automated/ dynamic tuning of PID controllers [8][9].

3. SIMULATION AND RESULTS

Let us consider a plant with standard time delay function G_P and computed its step response in open loop configuration as well as in closed loop configuration using MATLAB scripts.

Transfer function

$G_P(S) = 0.1111e^{-1.012S}/1 + 0.7263S.$

From the frequency response of the system the value of $k_p, k_i,$ and k_d are obtained as

$k_p = \omega \sin(1.012\omega) - \cos(1.012\omega)$……………….(8)

$k_i = \frac{4\omega\, [\sin(1.012\omega) + \omega \cos(1.012\omega)]}{(\omega^2+4)}$……………………..(9)

$k_i = \frac{\omega\, [\sin(1.012\omega) + \omega \cos(1.012\omega)]}{(\omega^2+4)}$……………………..(10)

On solving above equations using dual locus diagram the transfer function is determined

$H(S) = \frac{0.1111\,(2.17S^2+10.19S+8.61)}{(0.7263S^2+S)}$………………………..(11)

The step response obtained for the said system using the transfer function command "tf(num,den)". Where $Num = 0.1111 * \left[k_p * T_d, k_p, \frac{k_p}{T_i}\right]$

$and\ Den = [0.7263, 1,0]$

The response reported by C. B. Kadu and C.Y.Patil[1] is shown in figure 3.

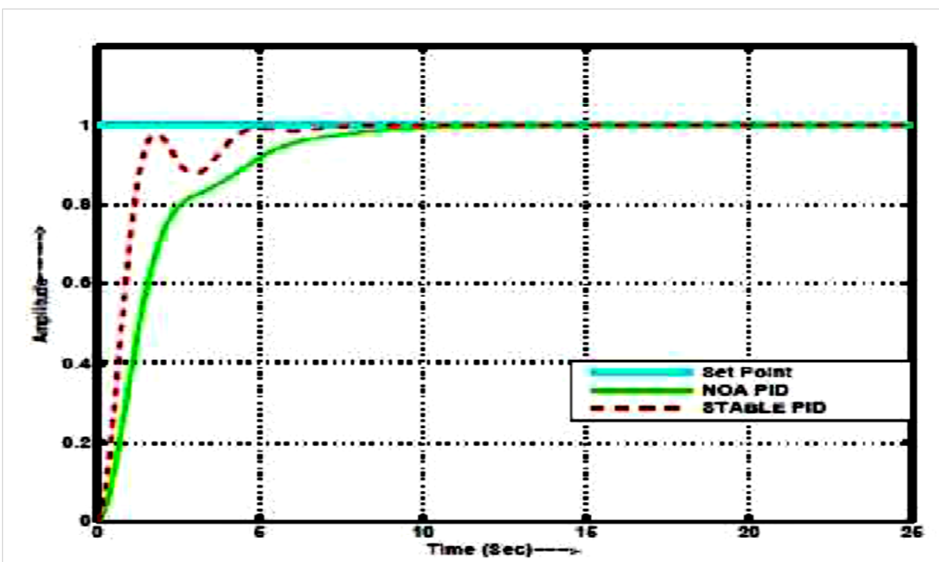

Figure 3: Step Response of time delay system with PID controller

The same plant is treated with a PID controller which is tuned according to Ziegler-Nichols method, Genetic Algorithm, and improved GA method in MATLAB. Here, responses corresponding to different tuning methods are presented only.

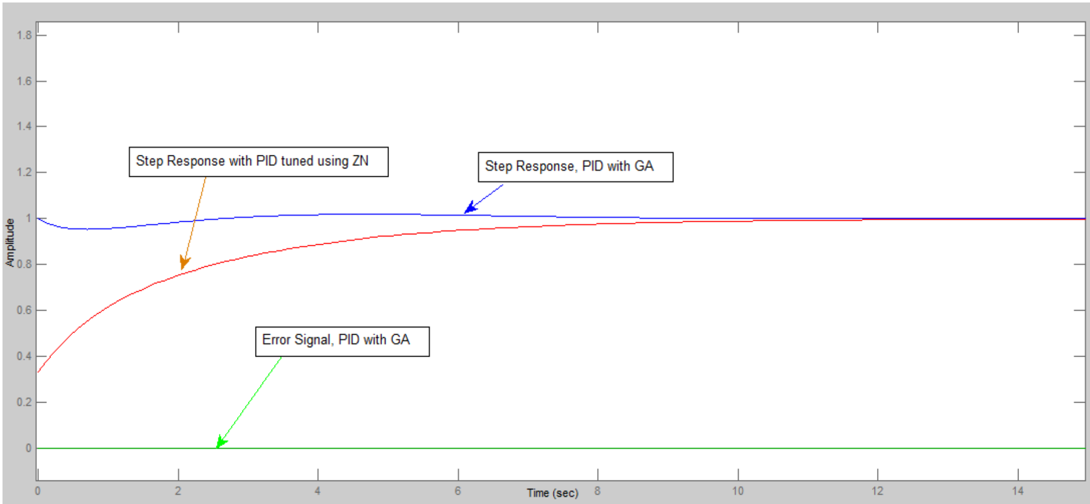

Figure 4: Closed loop response of the system with GA

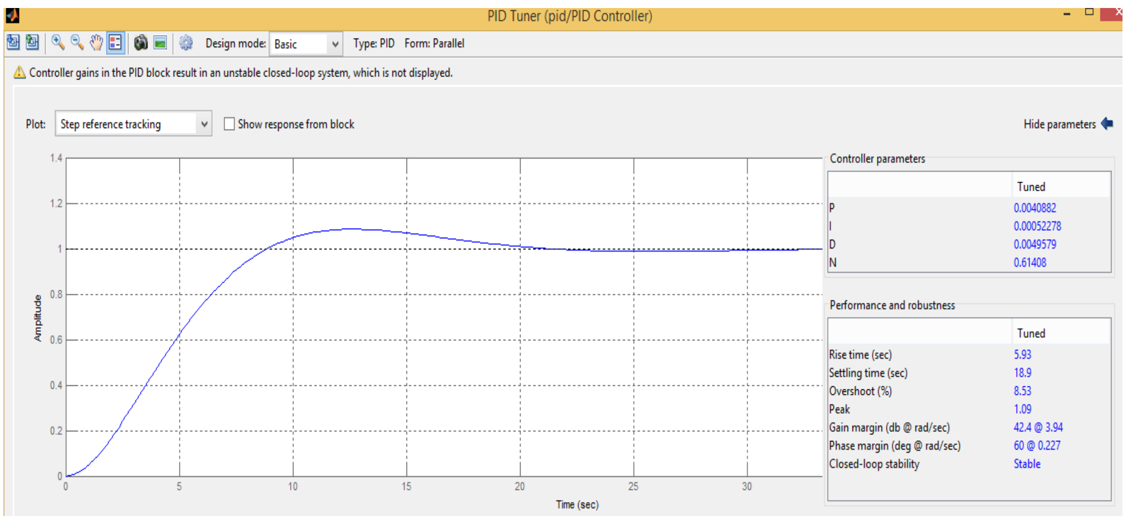

Figure 5: System Response with PID Auto Tuning

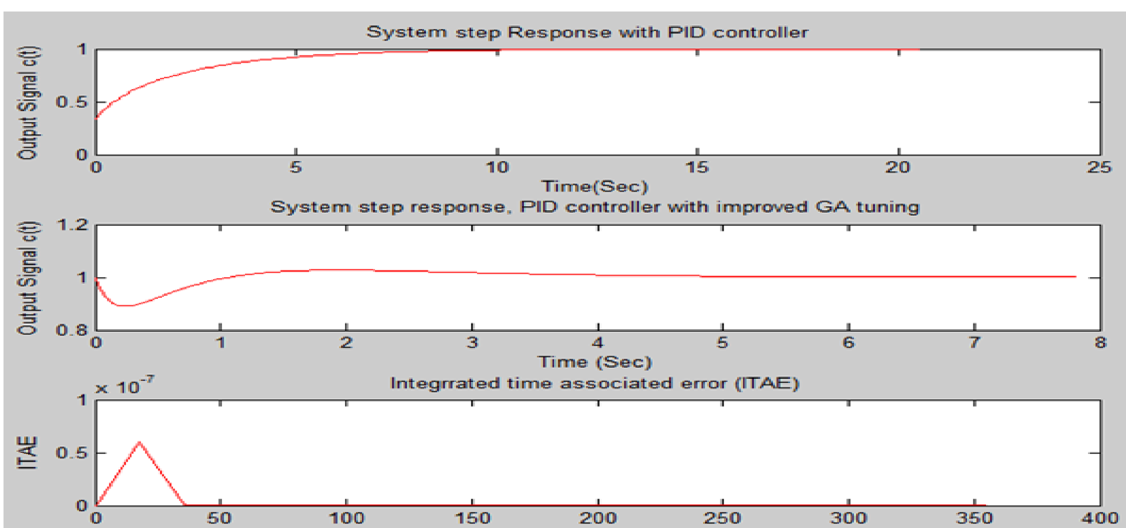

Figure 6: System response with improved GA

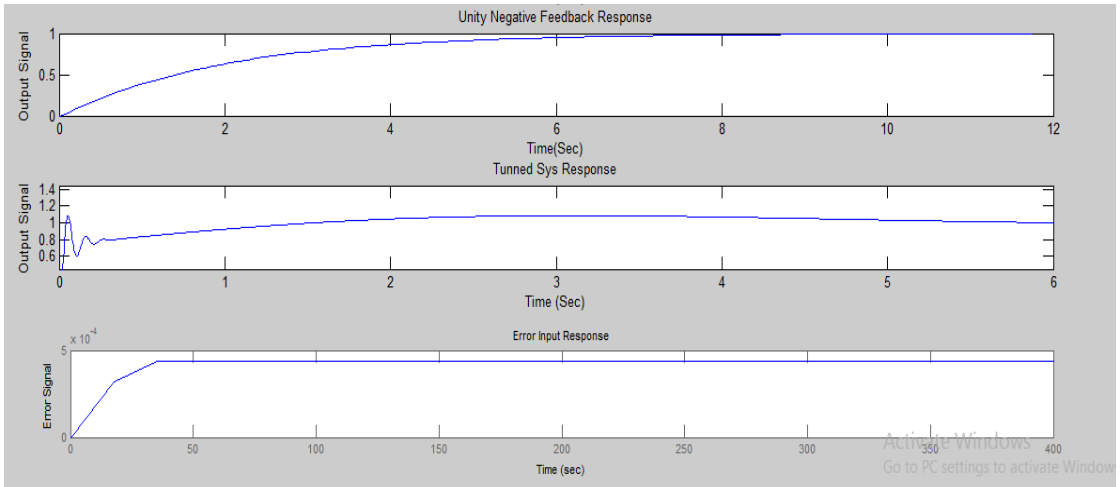

Figure 7: System step response for higher order plant

Step responses of other systems investigated through MATLAB Simulink are investigated successively. The system is a higher order system with complex transfer function. Here, all the computation done by MATLAB Simulink toolbox and shown in figures (8-12).

$$G_2(s) = \frac{500}{S^3 + 30S^2 + 1000S + 1}$$

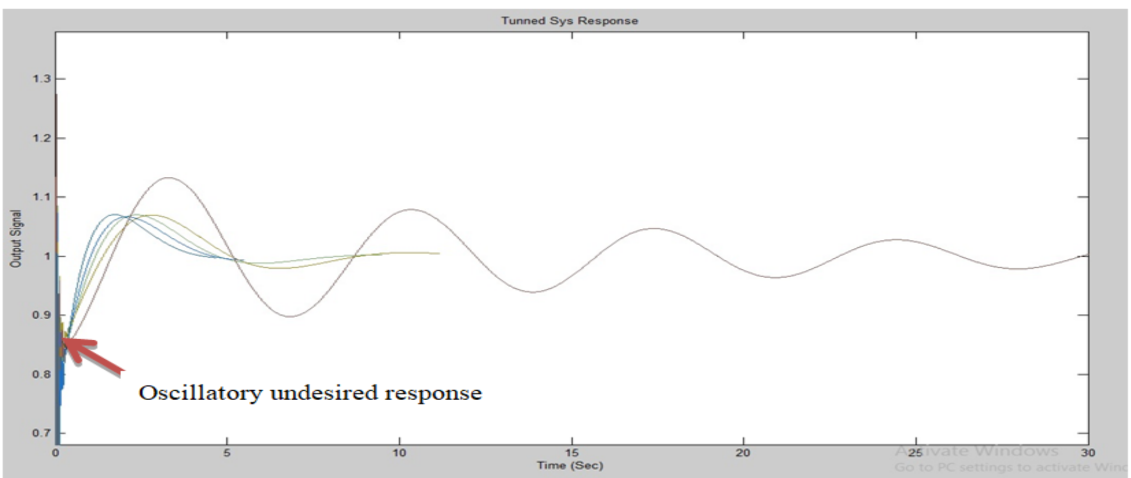

Figure 8: Set of responses corresponding to GA_fitness values

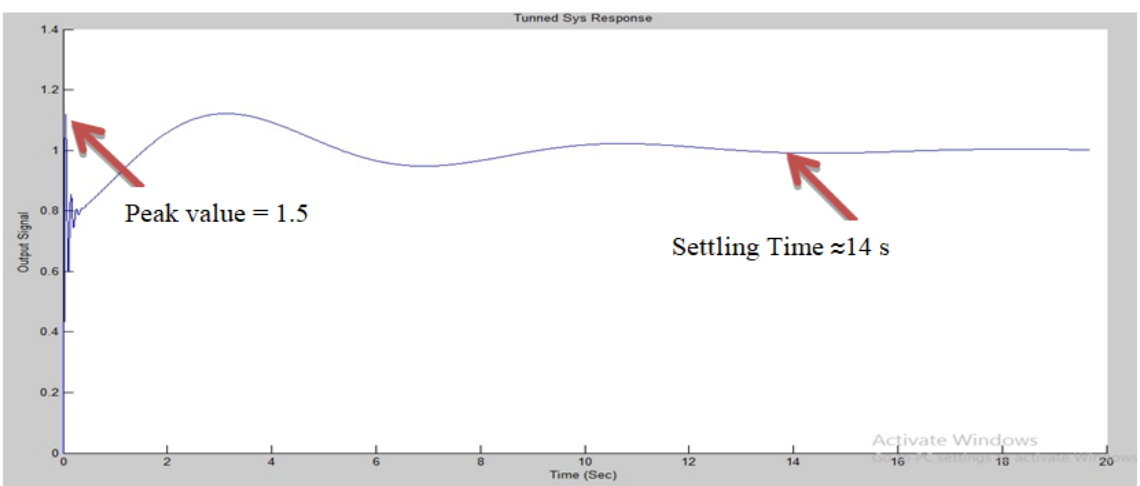

Figure 9: System responses with PID GA tuned method

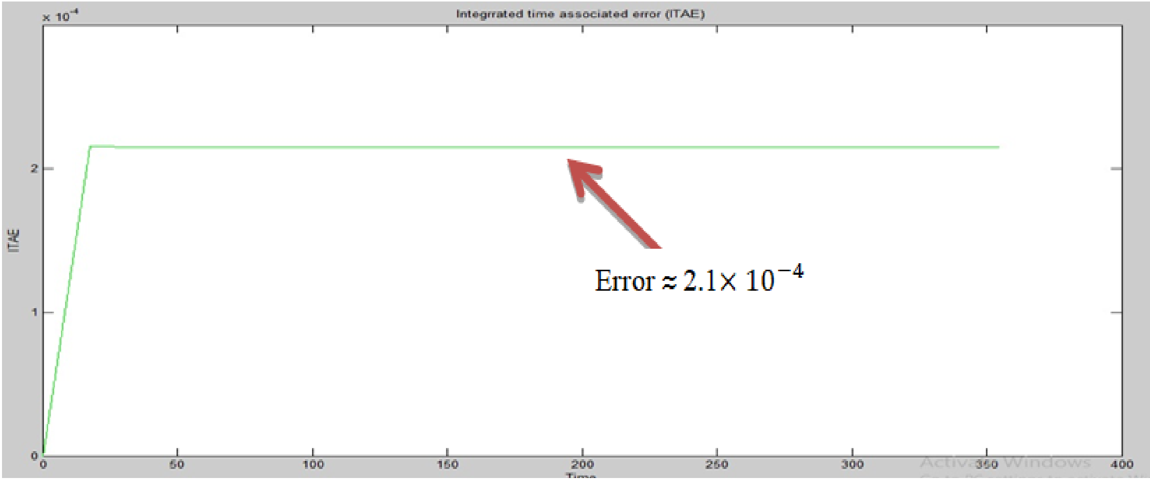

Figure 10: System errors in GA method

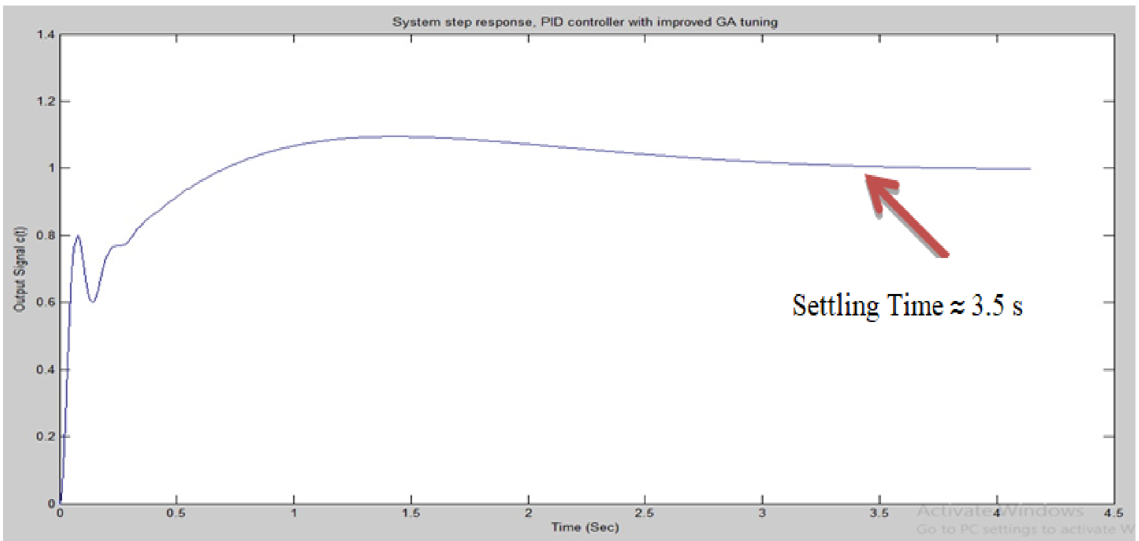

Figure 11: System responses Imp_GA method

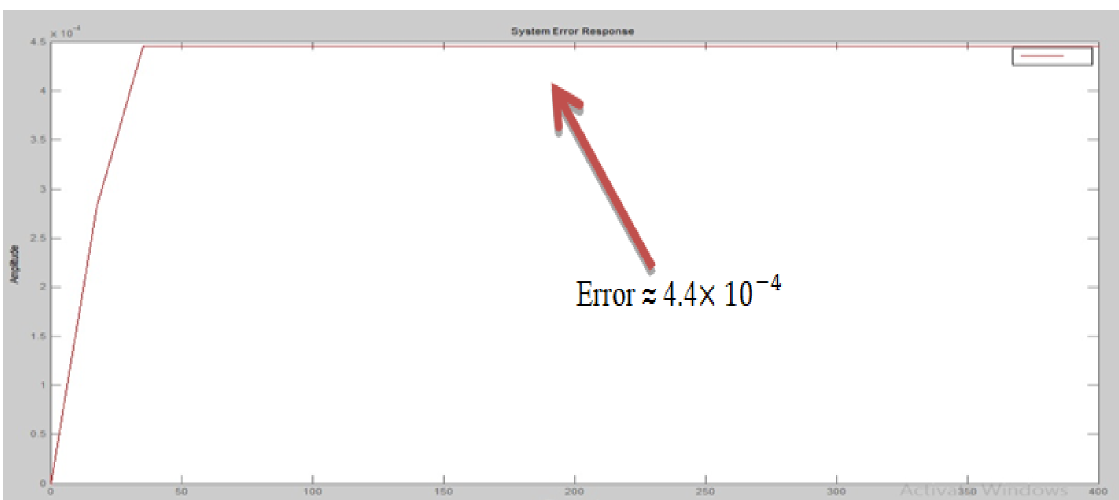

Figure 12: System errors in Imp_GA method

The figure 8, 9, and 10 represents responses corresponding to the different potential solutions, most promising solution, and range of error signal respectively using GA method. While figure 11 and 12 represents step response and error range respectively obtained through the improved genetic algorithm method. The results obtained provided better settling time and peak overshoot. The application of improved GA proved to be very satisfying results. Some other higher order unstable systems are also tested with this algorithm and that also found more promising results. Here ITAE represents the integrated time associated error. The parameters obtained from different techniques are compared in the table 1.

TABLE 1 COMPARATIVE RESULT OF FODT SYSTEM

Methods	k_p	k_i	k_d	τ_s	% Overshoot	ITAE	Time Elapsed
ZN	0.693	1.212	0.359	9.4850	0	16	-
AT	12.758	25.043	-2.450	6.4240	3.4376	10	-
GA	0.9047	0.9594	0.8296	10.1244	0	6	211.85 seconds
Imp_GA	0.3539	0.95	0.3472	3.2512	1.1424	1	37.76 seconds

TABLE 2 COMPARISON OF TUNED RESPONSE OF G2 SYSTEM

System	Rise Time (S)	Settling Time (S)	% Overshoot
ZN	7.67	8.92	0
GA	1.72	16.7	0
Imp_GA	0.76	3.5	1.1424

The table 2 compares parameters; rise time, settling time and peak overshoot computed through ZN, GA and Imp_GA and concluded that Imp_GA as best tuning method for a system using standard PID controller.

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