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Analysis and Comparison of different performance index factor for Conventional PID & GA plus PID Controller

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Abstract: The objective of this paper is to demonstrate an efficient method of tuning the PID controller parameters using the optimization rule for ITAE performance criteria. The method implies an analytical calculating the gain of the controller (K_c), integral time (T_i) and the derivative time (T_d) for PID controlled systems whose process is modeled in first order lag plus time delay (FOLPD) form. Firstly A mat lab program with objective function is written to find the optimum value for the PID controller parameters which can achieve most of the systems requirements such as reducing the overshoot, maintaining a high system response, achieving a good load disturbances rejection and maintaining robustness. The objective function is selected so as to minimize the integral of Time Absolute Error (ITAE) performance index. Using curve fitting technique, equations that define the controller parameters is driven. A comparison between the proposed tuning rules and the traditional tuning rules is done through the Matlab software to show the efficiency of the new tuning rule. The procedure has been successfully tested and some results are obtained. This paper presents a research work on a dynamic system by using a PID Controller, used to provide the simplest and yet effective solutions to most of the control engineering applications today and some computing algorithm, which is implemented in hardware for obtaining parameters of PID controller.

Key Words : ITAE criteria; ITSE; ISE; IAE; PID Controller; Z-N tuning rule; Genetic Algorithm (GA).

I. Introduction

Controlling the process is the main issue that rises in the process industry. It is very important to keep the process working probably and safely in the industry, for environmental issues and for the quality of the product being processed. In order for the controllers to work satisfactorily, they must be tuned probably. Tuning of controllers can be done in several ways, depending on the dynamics desired strengths of the system, and many methods have been developed and refined in recent years. The proportional-integral-derivative (PID) controller is widely used in the process industries. The main reason is their simple structure, which can be easily understood and implemented in practice. Finding design methods that lead to the optimal operation of PID controllers is therefore of significant interest. It has been stated, for example, that 98% of control loops in the pulp and paper industries are controlled by PI controllers (Bialkowski, 1996) and that, in more general process control applications, more than 95% of the controllers are of PID type (Åström and Hägglund, 1995). In order for the PID controller to work probably it has to be tuned which mean a selection of the PID controller parameters has to be made [8]. The requirement to choose either two or three controller parameters has meant that the use of tuning rules to determine these parameters is popular. There are many tuning rules for the PID controller as it has been noted that 219 such tuning rules in the literature to specify the PI controller terms, with 381 tuning rules defined to specify the PID controller parameters (O'Dwyer, 2003), Though the use of tuning rules is practically important [3, 11]. Even though, recent surveys indicate, 30 % of installed controllers operate in manual, 30 % of loops increase variability, 25 % of loops use default settings and 30 % of loops have equipment problems [1, 10]. Most PID tuning rules are based on first-order plus time delay assumption of the plant hence cannot ensure the best control performance. Using modern optimization techniques, it is possible to tune a PID controller based on the actual transfer function of the plant to optimize the closed-loop performance. In this paper optimization method is being used to obtain PID controller parameters. A search of one parameter to be optimized lead to select the Integral of Time multiply by Absolute Error (ITAE) index performance criterion, since it can provide controllers with a high load disturbance rejection and minimize the system overshoot while maintain the

robustness of the system. The Integral of Time multiply by Absolute Error (ITAE) index is a popular performance criterion used for control system design. In this paper it is proved that ITAE is better from the other index factor.

II. Controller Tuning

Controller tuning methods provide the controller parameters in the form of formulae or algorithms. They ensure that the obtained control system would be stable and would meet given objectives. Also, great advances on optimal methods based on stabilizing PID solutions have been achieved. These methods require certain knowledge about the controlled process. This knowledge, which depends on the applied method, usually translates into a transfer function [9]. In fact, since Ziegler–Nichols proposed their first tuning rules [5], an intensive research has been done from modifications of the original tuning rules to a variety of new techniques: analytical tuning; optimization methods; gain and phase margin optimization, just to mention a few. Recently, tuning methods based on optimization approaches with the aim of ensuring good stability and robustness has received attention in the literature [2, 6]. In this section some of PID tuning algorithms is considered.

A. Ziegler-Nichols tuning rule

Ziegler-Nichols tuning rule was the first such effort to provide a practical approach to tune a PID controller. According to the rule, a PID controller is tuned by firstly setting it to the P-only mode but adjusting the gain to make the control system in continuous oscillation. The corresponding gain is referred to as the ultimate gain (K_u) and the oscillation period is termed as the ultimate period (P_u). Then, the PID controller parameters are determined from K_u and P_u using the Ziegler-Nichols tuning table.

Table 1:- Ziegler-Nichols tuning rule

Controller	K_c	T_i	T_d
P	$K_u/2$		
PI	$K_u/2.2$	$P_u/1.2$	
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

The key step of the Ziegler-Nichols tuning approach is to determine the ultimate gain and period [5]. However, to determine the ultimate gain and period experimentally is time consuming.

III. The Proposed Tuning Rule

The proposed tuning rule is driven using several steps

Step 1:- Find relations between the controller tuning parameters and process parameters as stated below:-

$$K_c = f_1(K_P; L; T);$$

$$T_i = f_2(K_P; L; T);$$

$$T_d = f_3(K_P; L; T)$$

Function f_1 , f_2 and f_3 should be determined such that the load disturbances response is minimized and the robustness constraint is satisfied.

Step 2:- Create dimension less expressions through dividing and multiplying the factors of the process parameters with appropriate scale factors of each other such as L/T or T_i/L or T_i/T ; T_d/L or T_d/T ; $K_c \cdot K_P$

Step 3:- Select one factor of the above to find the relations between the tuning parameters and the process parameters. In this paper the factor (L/T) is being selected.

$$K_c \cdot K_P = K_1 (L/T); T_i/L = K_2 (L/T); T_d/L = K_3 (L/T)$$

Step 4:- For a defined values of the factor L/T determine the optimal value of the tuning parameters K_c ; T_i ; T_d which minimize a specific performance criteria (ITAE). In order to take FOPDT processes with a very small, medium and fairly long value of dead time into account, the values of the dimensionless factor L/T are considered from 0.1 to 2.

Step 5:- Find the values of $K_c \cdot K_P$; T_i/L ; T_d/L corresponding to the values of L/T .

Step 6:- Drive the equations of K1; K2; K3 using curve fitting techniques.

In step 4 a Matlab m-file is defined to calculate the ITAE index (the objective function) which is mathematically given by:-

$$ITAE = \int_0^{\infty} (t|e(t)|)dt$$

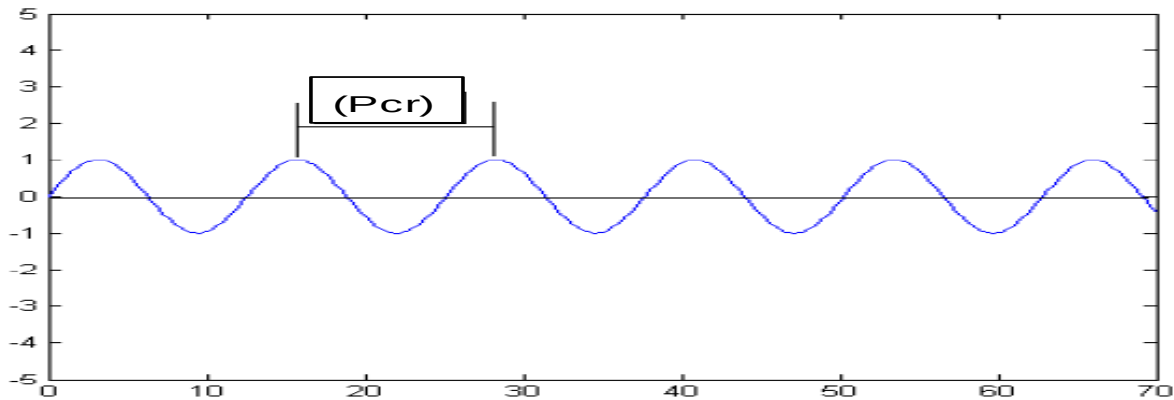
Where t is the time and e (t) is the error which is calculated as the difference between the set point and the output. A function of Matlab optimization toolbox (fminsearch) is called to calculate the minimum of the objective function. Like most optimization problems, the control performance optimization function is needed to be initializing and a local minimum is required. To do so, the initial controller parameters are set to be determined by one of existing tuning rules. In this way, the controller derived is at least better than that determined by the tuning method. The stability margin based Ziegler-Nichols is used for initial controller parameters and for performance comparison.

On each evaluation of the objective function, the process model develop in the simulink is executed and the IATE performance index is calculated using multiple application Simpson's 1/3 rule. The simulation s repeated with different values of the process parameters (T; L; KP).

A. Designing PID Parameters

From the response below, the system under study is indeed oscillatory and hence the Z-N tuning rule based on critical gain (Kcr) and critical period (Pcr) can be applied.

Figure 1. Illustration of Sustained Oscillation with Period Pcr

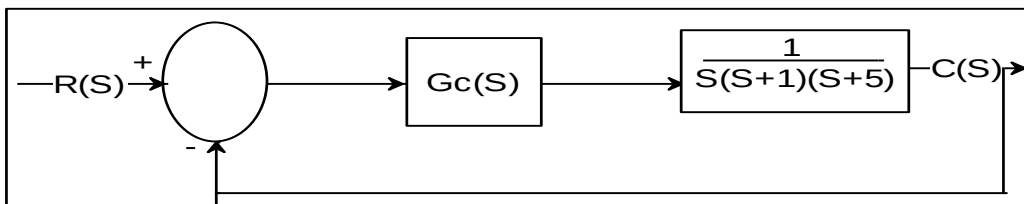


The transfer function of the PID controller is

$$G_c(s) = K_p (1 + 1/T_i s + T_d s)$$

The system under study above has a following block diagram

Figure 2. Block Diagram of Controller and Plant.



Since the $T_i = \infty$ and $T_d = 0$, this can be reduced to the transfer function of

$$\frac{C(s)}{R(s)} = \frac{K_p}{S(S+1)(S+5) + K_p}$$

The value of K_p that makes the system marginally stable so that sustained oscillation occurs can be obtained by using the Routh's stability criterion. Since the characteristic equation for the closed-loop system is

$$S^3 + 6S^2 + 5S + K_p = 0$$

From the Routh's Stability Criterion, the value of K_p that makes the system marginally stable can be determined

The table below illustrates the Routh array.

Table 2. Routh Array

S3	1	5
S2	6	K_p
S1	$(30 - K_p)/6$	0
S0	K_p	0

By observing the coefficient of the first column, the sustained oscillation will occur if $K_p=30$. Hence the critical gain (K_{cr}) is (K_{cr}) = 30. Thus with K_p set equal to K_{cr} , the characteristic equation becomes

$$S^3 + 6S^2 + 5S + 30 = 0$$

The frequency of the sustained oscillation can be determined by substituting the s terms with $j\omega$ term. Hence the new equation becomes

$$(j\omega)^3 + 6(j\omega)^2 + 5(j\omega) + 30 = 0$$

This can be simplified to

$$6(5 - \omega^2) + j\omega(5 - \omega^2) = 0$$

From the above simplification, the sustained oscillation can be reduced to

$$\omega^2 = 5$$

or

$$\omega = \sqrt{5}$$

The period of the sustained oscillation can be calculated as

$$(P_{cr}) = 2\pi/\sqrt{5} \\ = 2.8099$$

From Ziegler-Nichols frequency method of the second method [4], the table suggested tuning rule according to the formula shown. From these we are able to estimate the parameters of K_p , T_i and T_d .

Table 3. Recommended PID Value Setting.

Type of Controller	K_p	T_i	T_d
P	0.5 K_{cr}	∞	0
PI	0.45 K_{cr}	$(1/1.2) P_{cr}$	0
PID	0.6 K_{cr}	0.5 P_{cr}	0.125 P_{cr}

Hence from the above table, the values of the PID parameters K_p , T_i and T_d will be

$$K_p = 30 \\ T_i = 0.5 \times 2.8099 \\ = 1.405$$

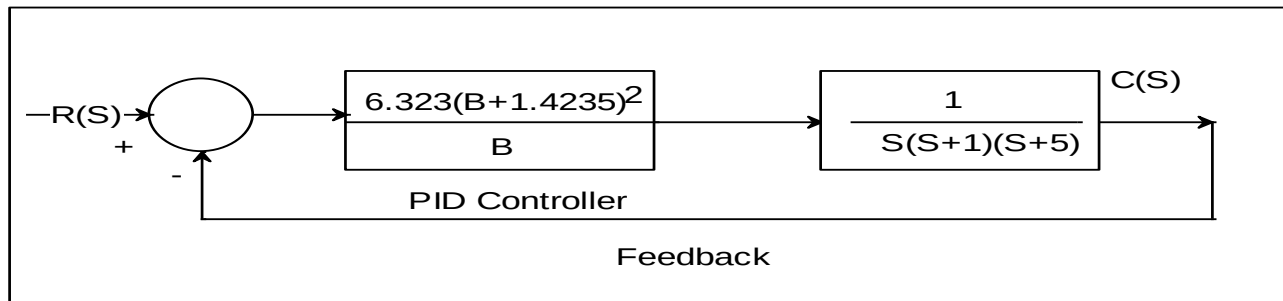
$$T_d = 0.125 \times 2.8099 \\ = 0.351.$$

The transfer function of the PID controller with all the parameters is given as

$$G_c(s) = K_p (1 + 1/T_i s + T_d s) \\ = 18 (1 + 1/1.405s + 0.35124s) \\ = 6.3223[(s + 1.4235)^2/s]$$

From the above transfer function, we can see that the PID controller has pole at the origin and double zero at $s = -1.4235$. The block diagram of the control system with PID controller is as follows.

Figure 3. Illustrated the Close Loop Transfer function.

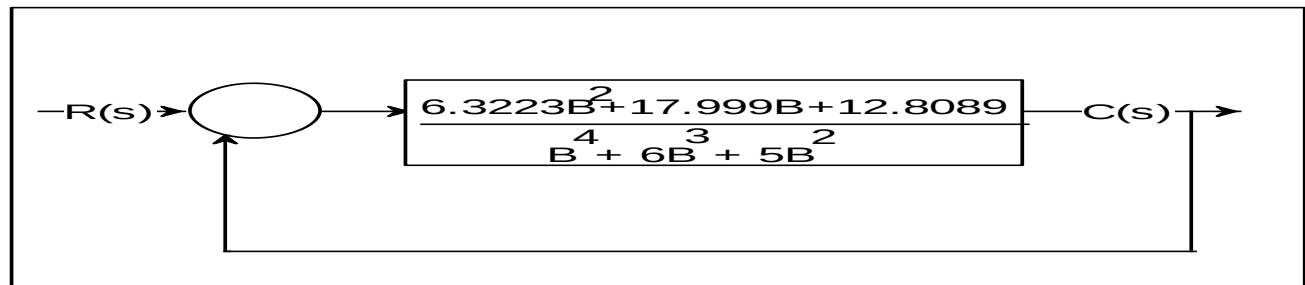


Using the MATLAB function, the following system can be easily calculated. The above system can be reduced to single block by using the following MATLAB function. Below is the Matlab codes that will calculate the two blocks in series. This will gives the following answer

$$\frac{\text{num}}{\text{den}} = \frac{6.3223S^2 + 17.999S + 12.8089}{S^4 + 6S^3 + 5S^2}$$

Hence the above block diagram is reduced to

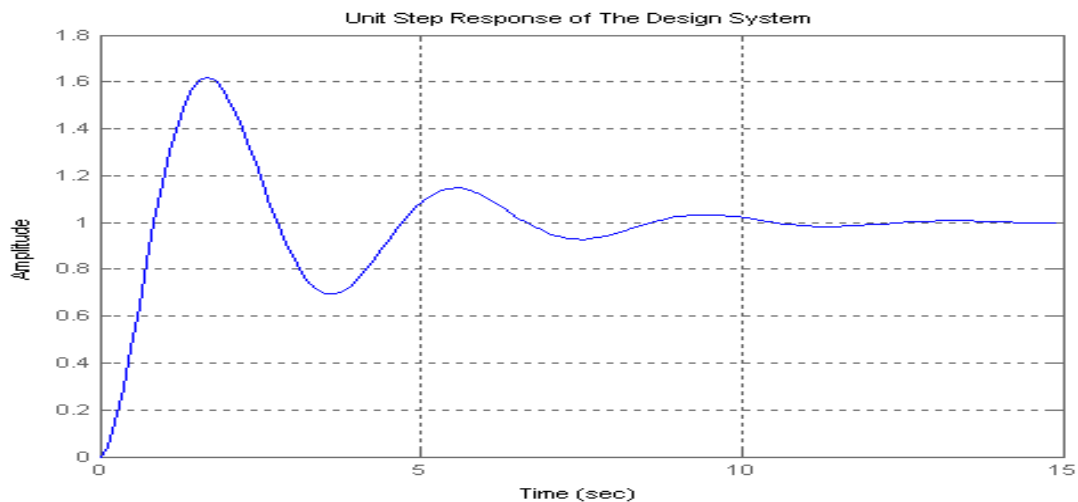
Figure 4. Simplified System.



Using another MATLAB function, the overall function with its feedback can be calculated as following graph obtained, as shown in fig.5

$$\frac{\text{Num}}{\text{Den}} = \frac{6.3223 S^2 + 17.999 S + 12.8089}{S^4 + 6 S^3 + 11.3223 S^2 + 17.999 S + 12.8089}$$

Figure5. Unit Step Response of the Designed System.



The figure above is the system response of the designed system. From the above response it is obvious that the system can be further improved.

IV. Methodology

From the above diagram, we can analyze the response of the system. The zero and pole of the system can be calculated using the MATLAB function `.tf2zp`. We can analyze them via the following parameters:

- Delay time, t_d
- Rise time, t_r
- Peak time, t_p
- Maximum Overshoot, M_p
- Settling time, t_s

The delay time, t_d of the above system which is the time taken to reach 50% of the final response time is about 0.5 sec. The rise time, t_r is the time taken to reach 5 to 95 % of the final value is about 1.75 sec. The Peak time, t_p is the time taken for the system to reach the first peak of overshoot is about 2.0 sec. The Maximum Overshoot, M_p of the system is approximately 60%. Finally the Settling time, t_s is about 10.2 sec. From the analysis above, the system has not been tuned to its optimum. Here we can improve the system by looking into the system zero and pole. The system zeros and poles can be calculated using MATLAB function and the output will be define as

Results:

```
z =
-1.4387
-1.4282
p =
-4.0478
-0.3532 + 1.5542i
-0.3532 - 1.5542i
-1.2457
k =
6.3223
```

The above result shows that the system is stable since all the poles are located on the left side of the s-plane. To optimize the response further, the PID controller transfer function must be revisited. The transfer function of the designed PID controller is

$$\begin{aligned} G_c(s) &= K_p (1 + 1/T_i s + T_d s) \\ &= 18 (1 + 1/1.405s + 0.35124s) \\ &= 6.3223 [(s + 1.4235)^2/s] \end{aligned}$$

The PID controller has a double zero of 1.4235. By trial and error, let keeps the $K_p = 18$ and change the location of the double zero from 1.4235 to 0.65.

The new PID controller will have the following parameters.

$$\begin{aligned} G_c(s) &= 18 (1 + 1/3.077s + 0.7692s) \\ &= 13.846[(s + 0.65)^2/s] \\ &= \frac{13.846s^2 + 17.996s + 5.85}{s} \end{aligned}$$

The PID transfer function and plant transfer function in series can be calculated by Matlab and the result as follows

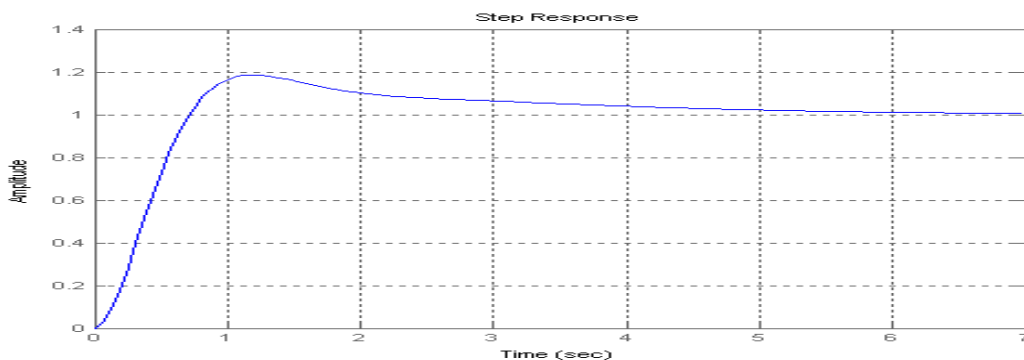
$$= \frac{13.846s^2 + 17.996s + 5.85}{s^4 + 6s^3 + 5s^2}$$

The total response with a unity feedback can be calculated as follow

$$\frac{R(s)}{O(s)} = \frac{13.846s^2 + 17.996s + 5.85}{s^4 + 6s^3 + 16.646s^2 + 17.996s + 5.85}$$

The response of the above system can be illustrated in the following plot.

Figure 6. Improved System Response.



The new system response has somehow improved. The Maximum Overshoot, M_p has reduced to approximately 18%. The Settling Time, t_s has improved from 14 sec to 6 sec. The Peak Time, t_p and Delay Time, t_d has increased. The final amplitude has improved at the expense of the system time. The new PID parameters can be calculated as are $K_p = 18$, $T_i = 3.077$ and $T_d = 0.7692$. To improve the system further, let's increase the K_p value to 39.42. The location of double zero will be kept the same i.e $s = -0.65$. The new transfer function of the PID controller will be

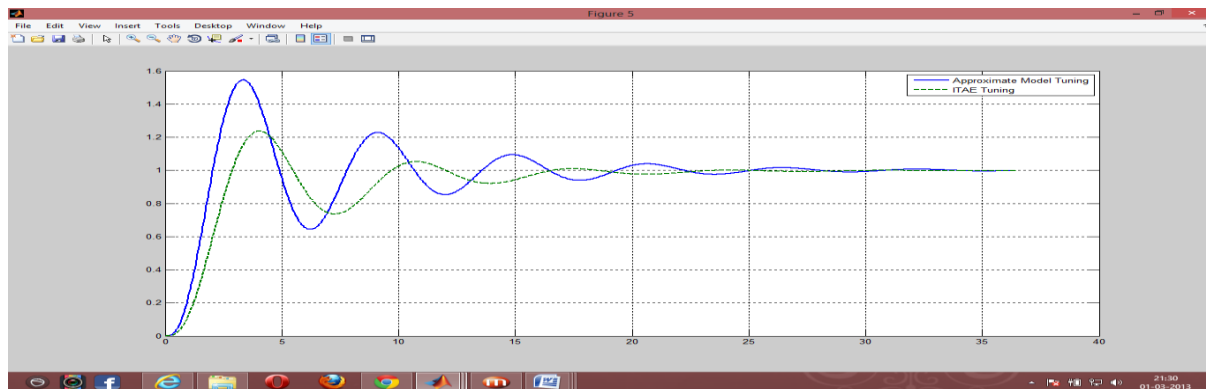
$$G_c(s) = 36 (1 + 1/8.977S + 0.769) \\ = 30.322 [(s + 1.4235)2 /s]$$

Using the Matlab command, the above function together with the plant transfer function and the unity feedback can be determined. The result is

$$G_c(s) = \frac{27.729s^2+36s+11.7}{s^4+6s^3+32.729s^2+36s+11.7}$$

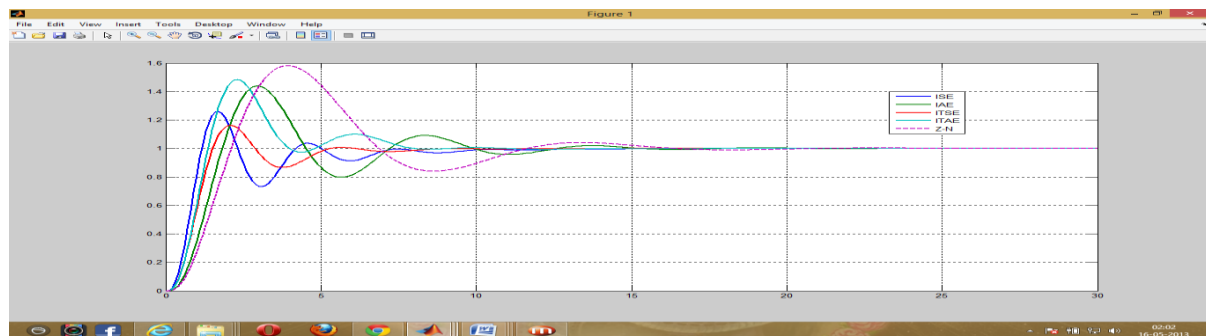
The system response can be shown as follow

Figure 7. Optimized System Response.



V. Mat lab Simulation Result

Figure 8. Initial value of Conventional PID Controller



Final Output:

Figure 9. Final index value of PID+GA Controller

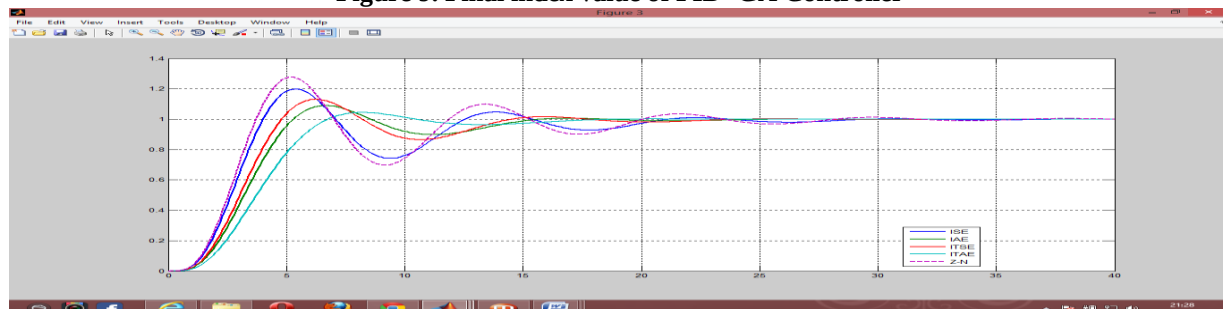


Table 4-.Comparison chart for PID performance index

Controllers	IAE	ISE	ITAE	ITSE	Rise Time(Sec)	Settling Time(sec)	Overshoot (%)
Convention al PID	1.42	1.24	1.49	1.18	04	14	20
PID+GA	1.09	1.2	1.02	1.16	03	15	05

VI. Conclusion

The above response shows that the ITAE is better performance index from the other threes. Because it takes only 1.02sec where other index are the higher values.. The response is faster than others shown in figure 9. The Maximum Overshoot, Mp has increased to about 20% to 05%. This is acceptable and best one since the Maximum Overshoot allowable is less than 25%.The Settling Time ts remain the same i.e. 14-15 sec. The Peak Time, tp and Delay Time, td has improved.

VII. References

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