A Novel Approach to Optimize System Response of a PID Controller

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***Abstract*: The objective of this paper is to achieve a unit-step response curve of the designed system that exhibits a maximum overshoot of 25 %. If the maximum overshoot is excessive says about greater than 40%, fine tuning should be done to reduce it to less than 25%. The system has been applied to a PID Controller system with variable plant transfer function. 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 :* Direct Digital Control (DDC), Distributed Control System (DCS), Genetic Algorithm (GA), PID Controller.**

I. Introduction

For the system under study, Zieger-Nichols tuning rule based on critical gain (Kcr) and critical period (Pcr) will be used. In this method, the integral time (Ti) will be set to infinity and the derivative time (Td) to zero. This is used to get the initial PID setting of the system. This PID setting will then be further optimized using the steepest descent gradient method. In this method, only the proportional control action will be used. The Kp will be increase to a critical value (Kcr) at which the system output will exhibit sustained oscillations. In this method, if the system output does not exhibit the sustained oscillations hence this method does not apply.

. PID controller consists of Proportional Action, Integral Action and Derivative Action. It is commonly refer to Ziegler-Nichols PID tuning parameters. It is by far the most common control algorithm. PID controller algorithms are mostly used in feedback loops. PID controllers can be implemented in many forms. It can be implemented as a stand-alone controller or as part of Direct Digital Control (DDC) package or even Distributed Control System (DCS) [1]. The latter is a hierarchical distributed process control system which is widely used in process plants such as pharceumatical or oil refining industries.

In proportional control,

Pterm = KP ×Error

It uses proportion of the system error to control the system. In this action an offset is introduced in the system.

In Integral control,

Iterm = KI ×∫Error dt

It is proportional to the amount of error in the system. In this action, the I-action will introduce a lag in the system. This will eliminate the offset that was introduced earlier on by the P-action.

In Derivative control,

$$\text{Dterm} = \frac{\text{KD} \times d(\text{Error})}{dt}$$

It is proportional to the rate of change of the error. In this action, the D-action will introduce a lead in the system. This will eliminate the lag in the system that was introduced by the I-action earlier on.

The concept of Genetic Algorithm (GA) comes from the Darwinian idea of natural selection and survival of fittest [2]. For a genetic algorithm to improve a solution, it is necessary to reject the poor solutions and only allow reproduction from the best ones. In this case, the role of the environment is played by an evaluating function, measuring the degree of fitness of a candidate to problem requirements [3].

In this paper firstly the PID Controller will be explained with its objective function for optimization. Next we will describe the genetic algorithm principles and after that define how the PID Controller will be used in dynamic system.

II. Continuous PID Controller

The three controllers when combined together can be represented by the following transfer function.

$$G_{c(s)} = K\,(1 + 1/T_{is} + T_{ds})$$

This can be illustrated below in the following block diagram

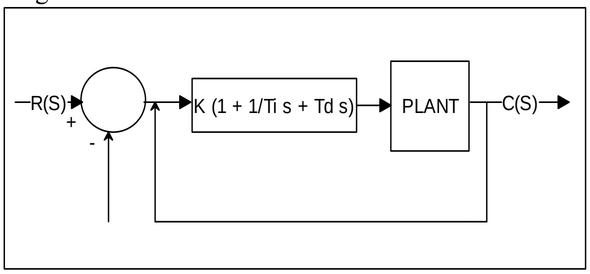

Figure 1.Block diagram of Continuous PID Controller.

What the PID controller does is basically is to act on the variable to be manipulated through a proper combination of the three control actions that is the P control action, I control action and D control action. The P action is the control action that is proportional to the actuating error signal, which is the difference between the input and the feedback signal. The I action is the control action which is proportional to the integral of the actuating error signal. Finally the D action is the control action which is proportional to the derivative of the actuating error signal. With the integration of all the three actions, the continuous PID can be realized. This type of controller is widely used in industries all over the world. In fact a lot of research, studies and application has been discovered in the recent years.

III. 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.

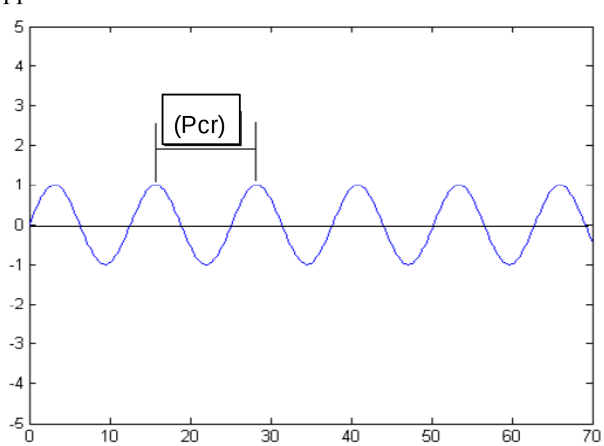

Figure 2. Illustration of Sustained Oscillation with Period Pcr

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

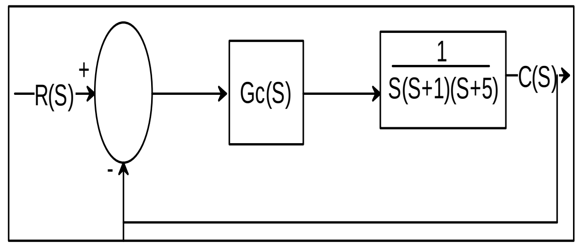

Figure 3. Block Diagram of Controller and Plant.

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 Kp 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 Kp that makes the system marginally stable can be determined

The table below illustrates the Routh array.

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

Table 1. Routh Array

By observing the coefficient of the first column, the sustained oscillation will occur if Kp=30.Hence the critical gain (Kcr) is (Kcr) = 30. Thus with Kp set equal to Ker, 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 jω term. Hence the new equation becomes

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

This can be simplified to

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

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.

Type of Controller	Kp	Ti	Td
P	0.5 Kcr	∞	0
PI	0.45 Kcr	(1/1.2) Pcr	0
PID	0.6 Kcr	0.5 Pcr	0.125 Pcr

Table 2. Recommended PID Value Setting.

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.

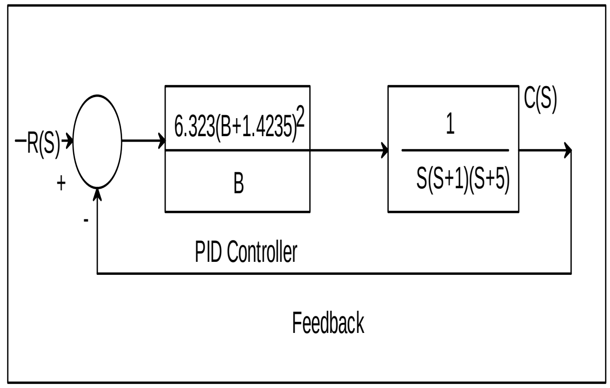

Figure 4. Illustrated the Close Loop Transfer function.

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

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

Hence the above block diagram is reduced to

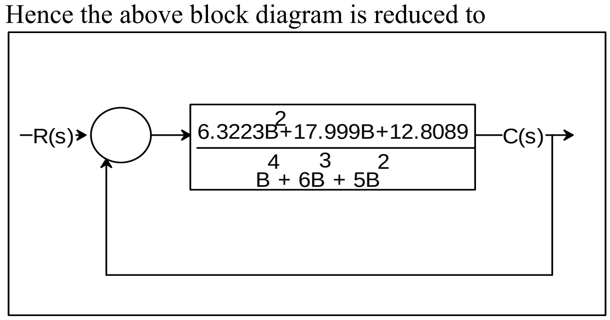

Figure 5. Simplified System.

Using another MATLAB function, the overall function with its feedback can be calculated as

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

From the unit step response function the

following graph obtained, as shown in fig.6

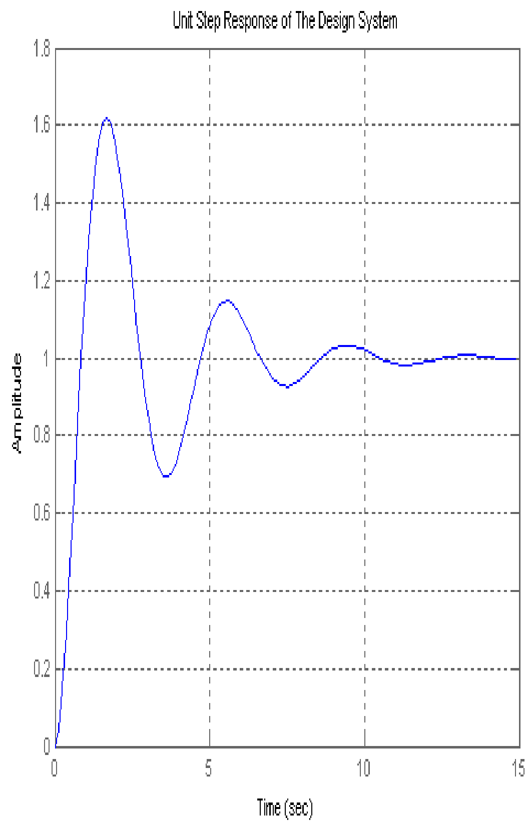

Figure 6. Unit Step Response of The Designed System.

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, Mp
- Settling time, t_s

The delay time, td 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, tp is the time taken for the system to reach the first peak of overshoot is about 2.0 sec The Maximum Overshoot, Mp of the system is approximately 60%. Finally the Settling time, ts 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

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

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

The new PID controller will have the following parameters.

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

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

$$= \quad 13.846s^2+17.996s+5.85$$

$S^4+6s^3+5s^2$

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.

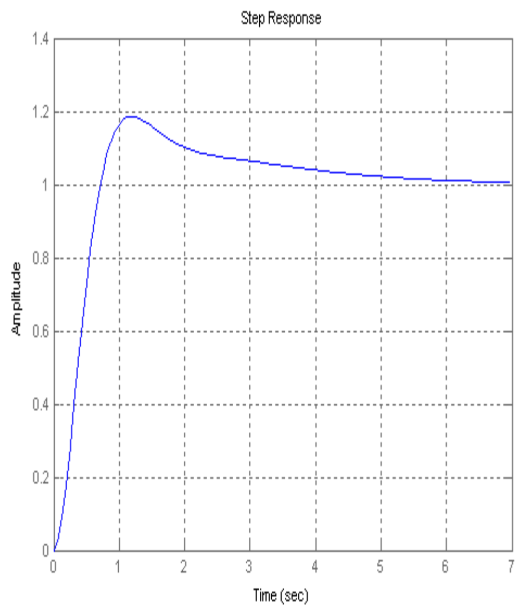

Figure 7. Improved System Response.

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, td 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, lets increase the Kp 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

V. FINAL RESULT

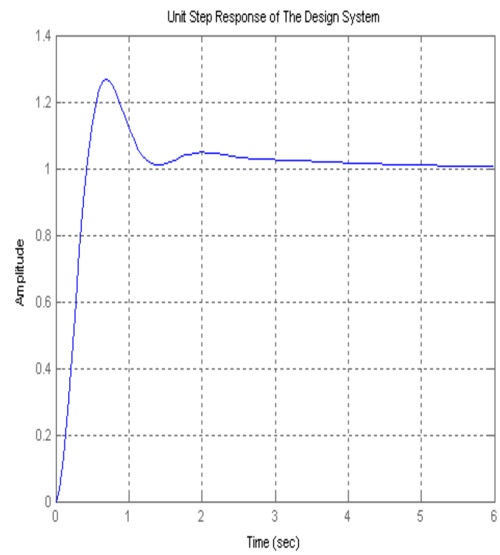

Figure 8. Optimized System Response.

VI. CONCLUSION

The above response shows that the system has improved. The response is faster than the one shown in figure 7. The Maximum Overshoot, Mp has increased to about 22%. This is still acceptable since the Maximum Overshoot allowable is less than 25%.The Settling Time ts remain the same i.e. 6 sec. The Peak Time, tp and Delay Time, td has improved.

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