2011 International Conference on Advancements in Information Technology
With workshop of ICBMG 2011
IPCSIT vol.20 (2011) © (2011) IACSIT Press, Singapore

A Simple Approach to Design of Variable Parameter Nonlinear PID Controller

Omer Aydogdu and Mehmet Korkmaz +

Selcuk University, Department of Electrical and Electronics Engineering, Konya, Turkey

Abstract. The fixed parameters in traditional Proportional Integral Derivative (PID) controller that is proposed by Ziegler-Nichols and other researchers lead to poor performance for transient response or steady state response and it has bad value of performance indices. On the other hand, analysis and design of the nonlinear PID controller is very complicated and difficult in practice. In this paper, a dynamic PID controller that changes parameters over time according to the error response is proposed. Synthesis and analysis of the proposed PID controller is realized easily and the system shows good performance measurement from the simulations.

Keywords: Variable Parameter, Non-liner PID Control, Performance Indices, IAE, ISE, Ziegler-Nichols Methods

1. Introduction

The PID controller is the most common form of feedback. It became the standard tool. PID controllers are today found in all areas where control is used. The controllers come in many different forms. PID control is often combined with logic, sequential functions, selectors, and simple function blocks to build the complicated automation systems used for energy production, transportation, and manufacturing. PID controllers have survived many changes in technology, from mechanics and pneumatics to microprocessors via electronic tubes, transistors, integrated circuits. The microprocessor has had a significant influence on the PID controller. Practically all PID controllers made today are based on microprocessors. This has given opportunities to provide additional features like automatic tuning, gain scheduling, and continuous adaptation [1]. So, to improve the control quality, many scholars use nonlinear characteristics to modify traditional linear PID controller in recent years [2]. The change characteristics of the nonlinear functions accord with the ideal change process of the parameters, so the nonlinear PID (NPID) can achieve both good static and dynamic performances and improve the control quality [3].

In this study, the appropriate change relationship between the absolute error of the control object and the control parameters is analysed and nonlinear functions of Proportional (P), Integral (I) and Derivative (D) depending on error are presented respectively.

2. Design of PID Controller and Performance Indices

2.1. PID Controller

A typical structure of a PID control system is shown in Fig.1, where it can be seen that in a PID controller, the error signal e(t) is used to generate the proportional, integral, and derivative actions, with the resulting signals weighted and summed to form the control signal u(t) applied to the plant model.

A mathematical description of the PID controller is,

+ Corresponding author. Tel.: + 90 332 223 22 52; fax: +90 332 241 06 35
E-mail address: mkorkmaz@selcuk.edu.tr; oaydogdu@selcuk.edu.tr

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int e(t)dt + T_d\frac{de(t)}{dt}\right] \quad (1)$$

where u(t) is control input to the plant model, e(t) is error which is difference between actual output (y(t)) and desired input (r(t)), Kp is proportional gain, Ti is integral time constant and Td is derivative time constant.

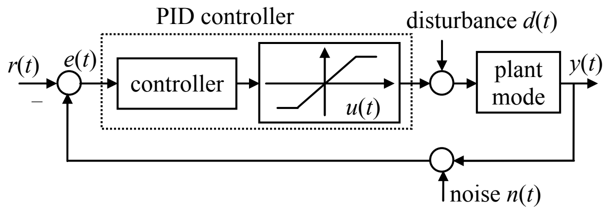

Fig. 1: A typical PID control

Determination of the Kp, Ti and Td constants is very important for the performance of the controller. It is presented different approaches to the determination of the constants in the literature by researchers.

2.2. PID Controller Design Methods

The most widely used design methods in the literature are Ziegler-Nichols rules, Chien-Hrones-Reswick PID tuning algorithm, Cohen-Coon tuning algorithm, Wang-Juang-Chan tuning formulae.

The Ziegler-Nichols design methods are the most popular methods used in process control to determine the parameters of a PID controller. Although these methods were presented in the 1940s, they are still widely used. Ziegler-Nichols tuning rule was the first such effort to provide a practical approach to tune a PID controller. Ziegler Nichols method (Z-N) is useful for plants of which mathematical models are unknown or difficult to obtain. This method guarantees the stability of the system [4].

There are two ways of implementing Ziegler-Nichols tuning rules. A parameter of system is chosen from the empirical tables which were created according to Z-N methods is used [5].

The Chien-Hrones-Reswick (CHR) PID tuning method emphasizes the set point regulation or disturbance rejection. In addition one qualitative specifications on the response speed and overshoot can be accommodated. Compared with the traditional Ziegler-Nichols tuning formula, the CHR method uses the time constant T of the plant explicitly [6]. Another tuning method of the PID controller is the Cohen–Coon tuning formula. This method is used a rule table that is obtained empirically as like Ziegler-Nichols rule table.

Based on the optimum ITAE criterion, the tuning algorithm proposed by Wang, Juang, and Chan is a simple and efficient method for selecting the PID parameters.

2.3. Performance Indices

A performance index is a quantitative measure of the performance of a system and is chosen so that emphasis is given to the important system specifications.

A performance index criterion given in eq.2 is a performance measures that is based on the integral of some function of the control error and on possibly other variables (such as time).

$$I = \int_0^T f(e(t), r(t), y(t), t)dt \quad (2)$$

To be useful as a performance measure, the integrand f(e,t) must be “positive definite”; that is f(e,t)≥0 for all values of error [7]. Some of the most commonly used integral criteria are as follows:

- Integral of the absolute error (IAE)
- Integral of the square error (ISE)

The smaller the value of the integral criterion, the better the performance of the control loop. Thus, when used as the basis for tuning a PID controller, the objective is to determine the values of the tuning parameters Kc , Ti , and Td that minimize the selected integral criterion. In this study IAE and ISE indices was used.

Integral of Absolute Error (IAE) is the integral of the control error, with all error treated as positive:

$$IAE = \int_0^T |e(t)| dt \tag{3}$$

Integral of Square Error (ISE) is the counterpart to the sum of squares from linear regression:

$$ISE = \int_0^T e^2(t) dt \tag{4}$$

The integral of the square error (ISE) penalizes for large errors more than for small errors. But in attempting to minimize this criterion function, responses with small errors will be accepted provided doing so will reduce the large errors. Often the response has a smaller initial overshoot, but the cycle does not decay rapidly. Basically several small peaks are tolerated to reduce the magnitude of the first peak. This type of behaviour is usually not desired in process loops.

3. Proposed Method

Analysing the above methods, it is always considered as fixed parameters of the PID controller. According to those methods, it is attempted to obtain the optimal values. Whereas in practise, given the transient and steady state responses of systems, fixed values of the temporary status at the time that the best solution does not sufficiently good results for the steady state response. Similarly, the best parameters of PID controller for the steady state response are not enough suitable for the temporary situation. Therefore, PID parameters can be dynamic by response and it is explicit that with today's digital control bodies. With this idea, variable parameters were defined in the following section for the PID controller and were determined change of the system response. Dynamic parameter curves were also determined considering being more effective for transient system as using proportional and derivative controller and for steady state system as using proportional and integral controller.

Considering the step response of a common control system we need to decrease overlapping and oscillation, accelerate the system response and initialize the steady state error. For these conditions the parameters can be analysed like this way:

In order to accelerate system response, proportional gain parameter (Kp) must be high firstly and then decrease to the normalized value (Fig. 3a).

Under these conditions the basic formula of K_p is:

$$K_p = c_1 + c_2.a \tag{5}$$

Kp range change of the c1 and c1+c2. To this, Kp minimum value is c1 and maximum value c1+ c2. In this formula, c1 and c2 real positive constants depend on the transfer function of the plant and ‘a’ term is the absolute of error value.

The derivative gain parameter (Kd) is increased to prevent the oscillation and overlapping. But, this increasing causes the slowdown the system response. Thus, change of Kd must be from the highest value to the lowest.

In a similar vein Kd can be formulized in the equation of the (6) for this Fig. 3b.

$$K_d = c_3 + c_4.a \tag{6}$$

Similarly, range of Kd is c3 and c3 + c4 and both of value is real positive constant.

Integral gain parameter (Ki) provides to initialize the steady state error but for the big values of this parameter causes the oscillation and higher overshoot. For this reason, Ki can change from minimum value to the normalized value (Fig. 3c)

In respect of Fig. 3 and characteristic of parameter Ki can be formulized like this way:

$$K_i = c_6 - c_5.a \tag{7}$$

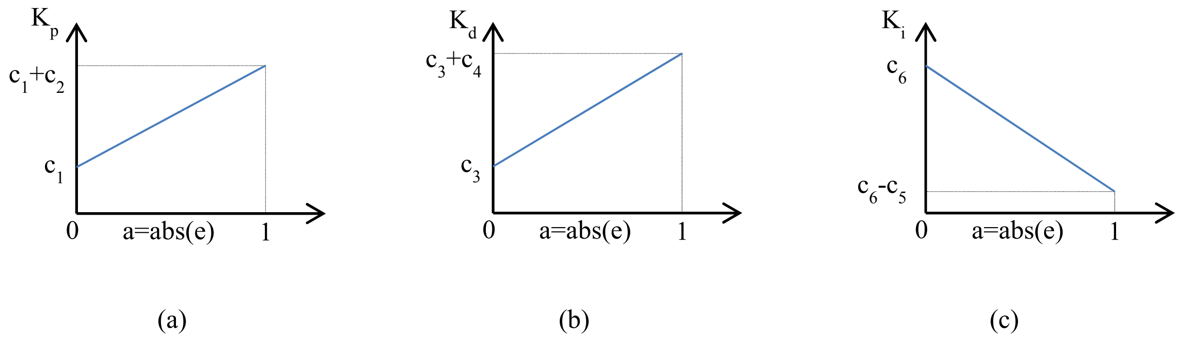

Fig. 3: Change of Kp, Kd and Ki to absolute of error

As it seen these analysis, we can provide the quick response system without overlapping and short settling time basically if the parameters adjust like above depending on the change of error.

4. Simulation Results

Implementing the control method mentioned in this paper, control system was compared with the classical common method Ziegler – Nichols and comparison of some results can be seen on Table II. Proposed method and Z-N values were investigated to some criterion and implementing method values better than Ziegler – Nichols methods.

In this study it was benefited from the below Matlab-Simulink model in Fig. 4. For this simulation two different plants model tested. The coefficients (c1,…,c6) shown in the Table I were obtained for both application. Error of steady state and performance indices were gotten and system response curves were figured for both. Examining by Table II, results of for both tried examples are better than Z-N methods. Two kind of plant was used in this paper which is third order process and first order time delay system.

$$G_1(s) = \frac{1}{s(s+2)(s+4)} \tag{8}$$

$$G_2(s) = \frac{e^{-0.3s}}{s+1} \tag{9}$$

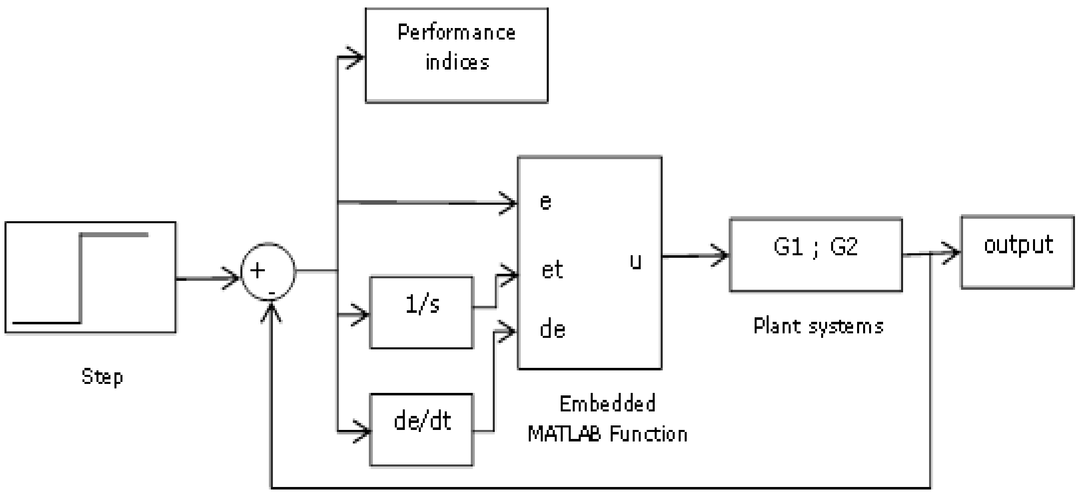

Fig. 4: Matlab Simulink Model

Table I: Coefficients For The Examples

	c1	c2	c3	c4	c5	c6
First Example	28.8	19.2	7.18	7.18	12.97	12.97
Second Example	2.4	1.62	0.3	0.3	3.34	3.34

Table II: Comparison values between Ziegler-Nichols and proposed methods

First Example	e_{ss}	IAE	ISE
Z-N Method	-0.00146	1.644	0.9363
Proposed Method	-0.00186	1.082	0.5398
Second Example			
Z-N Method	-0.00300	0.8643	0.4727
Proposed Method	-0.00001	0.5889	0.3955

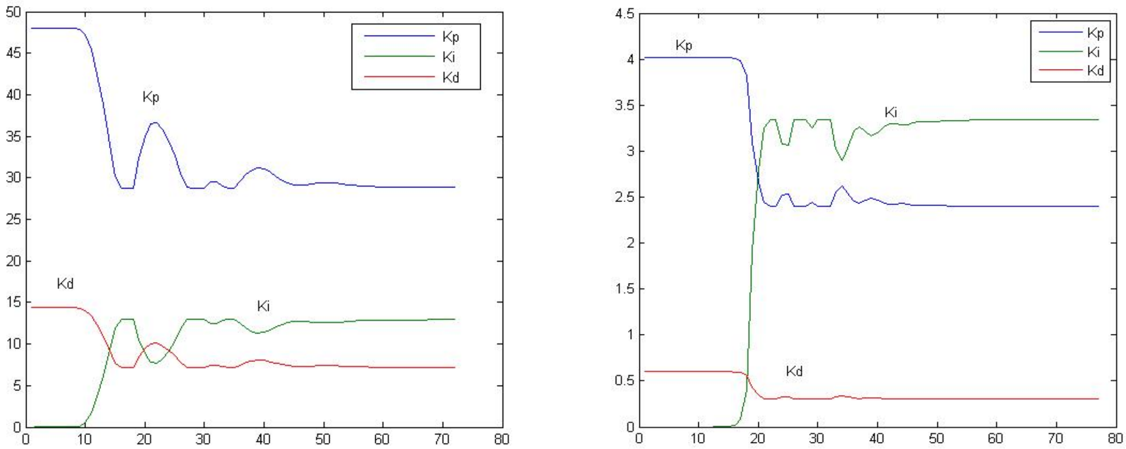

Fig. 5: (a) Changing of first example parameters (b) Changing of Second example parameters

5. Conclusions

Controllers designed by the Ziegler-Nichols rules, give closed loop systems with high overshoot and poor robustness. Therefore, the method results that it is not enough to control process dynamics smoothly. In order to decrease the disadvantages of ZN method, nonlinear PID approach was thought. Consequently, our method presents lower overlapping, short settling time than Ziegler – Nichols, for the third order systems. The simulation results show that nonlinear PID form, which is mentioned, how results have well. And this method is simple and effective beside this, these basic formulas can be used even microcontrollers which have the lower processors. In practice, this method can be implemented systems which are not higher speed and have no much memory since the calculations of Kp, Kd, Ki are basic.

6. Acknowledgment

This study is supported by Selcuk University Scientific Research Project Fund, BAP, under the contact number 11701825.

7. References

[1] Äström, K., Hägglund, T., 2002. Control System Design p.216, McGrawHill

[2] WANG Wei, ZHANG Jing-tao, CHAI Tian-you. A survey of advanced PID parameter tuning methods, Acta Automatica Sinica,Vol.26No.3. May, 2000. pp. 347-355.

[3] GU Jun-jie, ZHANG Yan-juan, GAO Da-ming, Application of Nonlinear PID Controller in Main Steam Temperature Control, Power and Energy Engineering Conference, APPEEC 2009, Asia-Pacific, 2009

[4] Ogata, K., 2002. Modern Control Engineering, , p. 683, Prentice Hall

[5] J. G. Ziegler and N. B. Nichols, "Optimum Settings for Automatic Controllers," Trans. ASME, Vol. 64, pp. 759-768, 1942.

[6] Dingyü Xue, Yang Quan Chen, Derek P. Atherton, Linear Feedback Control Analysis and Design with MATLAB p197, Society for Industrial and Applied Mathematics, Philadelphia

[7] Cecil L. Smith, Practical Process Control Tuning And Troubleshooting, Wiley, 2009