International Journal of Electrical and Electronics Engineers
Vol. No. 8, Issue No. 02, July-December 2016
ISSN (O) 2321-2055
ISSN (P) 2321-2045

APPLICATION OF ZIEGLER-NICHOLS METHOD FOR TUNING OF PID CONTROLLER

Vivek Kumar[1], Ashish Patra[2]

Electrical Engineering Department, MITS, Gwalior, (India)

ABSTRACT

PID controller, being the most widely used controller in industrial applications, needs efficientmethods to control the different parameters of the plant. Properly tuning the PID controller, i.e., setting its parameter values based on characteristics of the process it controls together with robustness criteria is commonly both timely and costly. The main focus of this paper is to apply ziegler-nicholsmethod tuning of PID controller to get an output with better dynamic and static performance. These methods are often used when the mathematical model of the system is not available. The Ziegler-Nichols method can be used for both closed and open loop systems.

Key Word—Control System, PID Controller, Ziegler-Nichols

I. INTRODUCTION

The PID controller is the most common controller in control systems. For example, in the mid 1990's the PID controller was used in over 95 % of the control loops in process control [1]. In the recent years, control system has assumed an increasingly important role in the development and advancement of modern civilization and technology. Practically every aspect of our day-to-day activities is affected by some type of control systems. Automatic control system are found in abundance in all sectors of industry, such as quality control of manufactured products, automatic assembly line, machine-tool control, space technology and weapon system, computer control, transportation systems, power systems, robotics and many others. It is essential in such industrial operations as controlling pressure, temperature, humidity, and flow in the process industries [2].

Within process industry, and in many other areas, the PID controller is responsible for handling regulatory control. An educated guess is that the number of executing PID control loops lies in the billions (2011) and there are no signs indicating a decrease of this number.

Properly tuning the PID controller, i.e., setting its parameter values based on characteristics of the process it controls together with robust-ness criteria is commonly both timely and costly. Hence, the tuning is often overseen, resulting in numerous poorly tuned loops. These result in unnecessary lack of performance, which might be both hazardous and uneconomic.

If a linear time invariant model of the process is given, there exist numerous feasible tuning methods. However, automatically obtaining even a low complexity model is far from trivial in the absence of a priori process information.

II LITERATURE SURVEY

Some of the technique/ approaches used to Tuning for PID controller by various researchers have been summarized here.

Hohenbichler et al. [3] has been offered A technique to compute the entire set of stabilizing PID controller parameters for a random (including unstable) linear time delay system. To handle the countless number of stability boundaries in the plane for a permanent proportional gain Kp was the most important contribution. It was illustrated that the steady area of the plane contains convex polygons for retarded open loops. A phenomenon was initiated concerning neutral loops. For definite systems and certain kp, the precise, steady area in the plane could be explained by the limit of a sequence of polygons with an endless number of vertices. This cycle might be fined fairly accurate by convex polygons. Moreover, they explained a needed condition for kp-intervals potentially containing a stable area in the plane. As a result, after gridding kp in these intervals, the set of stabilizing controller parameters could be planned.

Liang et al. [4] has been presented A partial order PID controller of robust constancy areas for interval plant with time delay. They have explored the problem of computing the robust constancy area for interval plant with time delay. The partial order interval quasi-polynomial was crumbling into a number of vertex attribute quasi-polynomials by the lower and upper bounds. To explain the constancy boundaries of every vertex attributes quasi-polynomial in the space of controller parameters, the D-decomposition method was employed. By overlapping the constancy area of each quasi polynomial, the constancy area of interval attribute quasi polynomial was found out. By choosing the control parameters from the constancy area, the parameters of their suggested controller were attained. The vigorous constancy was checked by means of the value set together with the zero elimination principle. Their suggested algorithm was constructive in examining and planning the robust PIkDl controller for interval plant.

Suji Prasad et al. [5] proposed a particle swarm optimized PID controller of Second Order Time Delayed System. Optimization was based on the presentation indices like settling time, rise time, peak overshoot, ISE (integral square error) and IAE (integral absolute error). PID controllers and its alternatives are most commonly used, although there are important improvements in the control systems in industrial processes. If the parameter of controller was not appropriately planned, next needed control output may not succeed. Compared with Ziegler Nichols and Arvanitis tuning, they have confirmed that their simulation results with optimized I-PD controller to be specified enhanced presentations.

Rama Reddy et al. [6] has been explained a PID controller for time delay systems. Their suggested technique pre´cised the stable areas of PID and a novel PID with cycle leading correction (SLC) for network control systems with time delay. The latest PID controller has a modification parameter 'b'. They have obtained that relation of the parameters of the system. The outcome of plant parameters on constancy areas of PID controllers and SLC-PID controllers in first-order and second-order systems with time delay is moreover pre´ cised. Finally, an open-loop zero was introduced into the plant unstable second order system with time delay so that the constancy areas of PID and SLC-PID controllers get competently made bigger.

Luo et al. [7] have suggested a part encloses in selecting two feasible or achievable patterns, and a FOPI/IOPID controller synthesis was applied for all the steady FOPTD systems. The entire possible area of two patterns can be attained and pictured in the plane by means of their suggested plan. Every mixture of two patterns can be confirmed before the controller design, with those areas as the previous knowledge In particular, it was fascinating to compare the regions of these two possible areas for the IOPID and FOPI controllers. A simulation picture demonstrates that their suggested plan has resulted and their presentation of the designed FOPI controller is compared to the optimized integer order PI controller and the planned IOPID controller.

Bouallegue et al. [8] have suggested to a novel PID-type fuzzy logic controller (FLC) tuning approaches from a particle swarm optimization (PSO) strategy. Two self-tuning methods were inserted so as to develop more the presentation and toughness properties of the suggested PID-fuzzy strategy. The scaling features tuning problem of these PID-type FLC configurations was created and steadily determined, by means of a suggested limited PSO algorithm. To show the competence and the supremacy of the suggested PSO-based fuzzy control strategies, the case of an electrical DC drive benchmark was explored, inside an improved real-time framework.

Shabib et al. [9] have explained about the power system nonlinear with frequent changes in operating areas. In excitation control of power systems, Analog proportional integral copied PID controllers were extensively employed. Fuzzy logic control was frequently out looked as a structure of nonlinear PD, PI or PID control. They moreover explained the design principle, tracking presentation of a fuzzy proportional integral PI plus derivative D controller. To integrate a fuzzy logic control mechanism into the alterations of the PID structure, this controller was improved by first explaining discrete time linear PID control law and subsequently more and more obtaining the steps required. The bilinear transform (Tustin's) was applied to discretize the conventional PID controller. In that some presentations criteria were employed for comparison between other PID controllers, such as settling times, overshoots and the amount of positive damping.

Ozbay et al. [10] possess created some sort of traditional appropriate PID controllers with regard to linear time period invariant facilities whoever transfer operates were logical operates connected with Sa, exactly where $0< a< 1$, and s is the Laplace transform variable. Effect connected with input– output time period delay about the range of allowed controller details has been perused. This allowed PID controller details were identified from a small acquire style of argument utilized sooner with regard to specific dimensional facilities.

Zhao et al. [11] proposed an Integral of Time Absolute Error (ITAE) zero-position-error optimal tuning and noise effect minimizing method for tuning two parameters in MD TDOF PID control system to own sought after regulatory as well as disturbance rejection overall performance. Your contrast together with Two-Degree-of-Freedom control program by modified smith predictor (TDOF CS MSP) and also the made MD TDOF PID tuned by the IMC tuning approach demonstrates the potency of the particular described tuning approach.

Feliu-Batlle et al. [12] proposed the latest technique for the control of water distribution in an irrigation main canal pool seen as substantial time-varying time delays. Time delays may perhaps adjust greatly in an irrigation main canal pool as a result of versions inside its hydraulic operations program. A classic system got its start to development fractional buy PI controllers coupled with Smith predictors that produce control systems which can be robust for the modifications in the process time delay. The system was given to fix the situation regarding powerful water submission control in an irrigation main canal pool.

Sahu et al. [13] have outlined around the design and style as well as effectiveness evaluation regarding Differential Evolution (DE) algorithm based parallel 2-Degree Freedom of Proportional-Integral-Derivative (2-DOF PID) controller for Load Frequency Control (LFC) of interconnected power system process. The planning issue has been formulated as an optimization issue and DE has been currently employed to look for optimal controller parameters. Standard as well as improved aim features have been used for the planning goal. Standard aim features currently employed, which were Integral of Time multiplied by Squared Error (ITSE) and Integral of Squared Error (ISE). To be able to additionally raise the effectiveness in the controller, some sort of improved aim operate is derived making use of Integral Time multiply Absolute Error (ITAE), damping ratio of dominant eigenvalues, settling times of frequency and peak overshoots with appropriate weight coefficients. The particular fineness in the recommended technique has become confirmed by simply contrasting the results with a lately published strategy, i.e. Craziness based Particle Swarm Optimization (CPSO) for the similar interconnected electric power process. Further, level of sensitivity evaluation has been executed by simply varying the machine details as well as managing load conditions off their nominal valuations. It is really observed which the recommended controllers are quite powerful for many the system parameters as well as managing load conditions off their nominal valuations.

Debbarma et al. [14] have suggested a new two-Degree-of- Freedom-Fractional Order PID (2-DOF-FOPID) controller ended up being suggested intended for automatic generation control (AGC) involving power systems. The controller ended up being screened intended for the first time using three unequal area thermal systems considering reheat turbines and appropriate generation rate constraints (GRCs). The simultaneous optimization of several parameters as well as speed regulation parameter (R) in the governors ended up being accomplished by the way of recently produced metaheuristic nature-inspired criteria known as Firefly Algorithm (FA). Study plainly reveals your fineness in the 2-DOFFOPID controller regarding negotiating moment as well as lowered oscillations. Found function furthermore explores the effectiveness of your Firefly criteria primarily based marketing technique in locating the perfect guidelines in the controller as well as selection of R parameter. Moreover, the convergence attributes in the FA are generally justified when compared with its efficiency along with other more developed marketing technique such as PSO, BFO and ABC. Sensitivity analysis realizes your robustness in the 2-DOF-FOPID controller intended for distinct loading conditions as well as large improvements in inertia constant (H) parameter. Additionally, the functionality involving suggested controller will be screened next to better quantity perturbation as well as randomly load pattern.

III PID CONTROLLER TUNING METHODS

Ziegler and Nichols were proposed PID controller tuning methods in 1942 and have been widely utilized either in the original form or in modified forms. Different types of PID controller tuning methods discuss detailed in below [15]

3.1 Step Response (Open Loop) Method

The Ziegler-Nichols step response method is the classical tuning methods for PID controllers. They were presented already in 1942, but they are still widely used in the process industry as the basis for controller tuning [16-17]. The step response method is based on an open-loop step response test of the process, hence requiring the process to be stable. The unit step response of the process is characterized by two parameters, *L* and *T*. These are determined by drawing a tangent line at the inflexion point, where the slope of the step response has its maximum value. The intersections of the tangent and the coordinate axes give the process parameters as shown in Figure 1, and these are used in calculating the controller parameters.

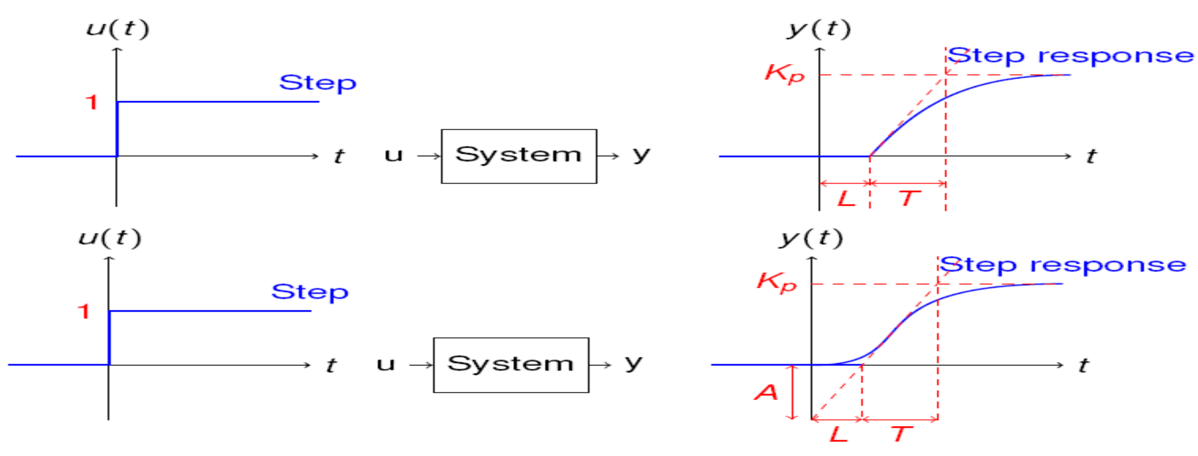


Figure 1: S Shaped Response Curve for Ziegler-Nichols Tuning Algorithm

International Journal of Electrical and Electronics Engineers
Vol. No. 8, Issue No. 02, July-December 2016
ISSN (O) 2321-2055
ISSN (P) 2321-2045

The parameters for P, PI and PID controllers obtained from the Ziegler-Nichols step response method are shown in Table 1.

Table1: Ziegler–Nichols tuningformulae– Step Response Method

ControllerType	K_p	T_i	T_d
P	T/L		
PI	0.9 T/L	$\frac{L}{0.3}$	
PID	1.2 T/L	$2L$	$0.5L$

3.2 Closed Loop (Sustain Oscillation) Method

The procedure is as follows: -

- Select proportional control (K_p) alone .
- Increase the value of the proportional gain (K_p)until the point of instability is reached (sustained oscillations), the critical value of gain(K_{cr}), is reached.
- Measure the period of oscillation to obtain the critical time constant (P_{cr}).
- Once the values for K_{cr} andP_{cr} are obtained, the PID parameters can be calculated, according to the design specifications as shown in (Table 2).

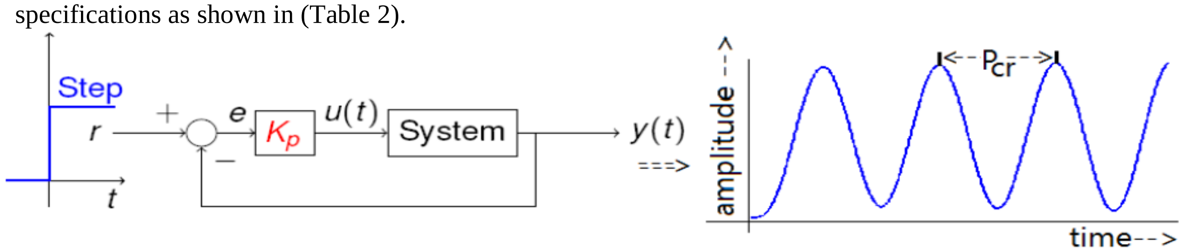


Figure 2: Sustained Oscillation Method for Ziegler-Nichols Tuning

Table2: Ziegler–Nichols tuningformulae – Sustain OscillationMethod

ControllerType	K_p	T_i	T_d
P	$0.5K_{cr}$		
PI	$0.45K_{cr}$	1/1.2 P_{cr}	
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

IV NUMERICAL RESULT AND DISCUSSION

In order to assess the effectiveness of the proposed algorithms, the system in Eq. 1, is assumed as the transfer function of our plant. However any system with a transfer function can be used as a process to be controlled.

$$\text{Plant} = 10/(s+4)(s+5)(s+6)(s+8) \quad (1)$$

The PID controller shown in Eq.2 is known as the ideal or non-interacting form of PID controller. This form of PID Controller is used in this report and also in MATLAB Scripts used here.

$$u(t) = [K_p(1 + \frac{1}{T_i} + T_d s)] \quad (2)$$

Another form of PID Controller is parallel form Eq. 3,

$$u(t) = [K_p + \frac{K_i}{T_i} + K_d s] \quad (3)$$

To demonstrate the effectiveness of the proposed algorithm, two different cases have been considered as follows:

4.1 Empirical Ziegler-NicholsTuningAlgorithm

4.1.1 Step Response ('S' Shaped) Curve/Process Reaction Curve Method

4.1.2 Sustained Oscillation Method

In this case the three actions are completely separated. Actually, the parallel form is the most general of the different forms, as it allows to exactly switch off the integral action by fixing $K_i = 0$ (in the other cases the value of the integral time constant should tend to infinity).

The transfer function representation of the approximate PID controller can be written as Eq. 4.

$$u(t) = \left\{K_p[1 + \frac{1}{T_i} + \frac{T_d s}{1 + s\frac{T_d}{N}}\right\} e(s) \quad (4)$$

The PID controller with feedback H (s), can be described as Eq. 5.

$$H(s) = \left\{\frac{\left(1+\frac{K_p}{N}\right)T_i T_d s^2 + K_p\left(T_i + \frac{T_d}{N}\right) + K_p}{K_p(T_i s + 1)\left(1 + \frac{T_d s}{N}\right)}\right\} \quad (5)$$

4.2 CASE 1: EMPIRICALZIEGLER-NICHOLSTUNINGALGORITHM

To Study the Empirical Ziegler-Nichols Tuning Algorithm and designing the P, I and D parameter for the Plant described as in Eq.4.1.

4.2.1 Step Response ('S' Shaped) Curve/Process Reaction Curve Method:

The Parameter for evaluating the values of the PID Controller as given in Table 2, can be obtained from Figure 3. The obtained parameters are: K= 0.4167, L= 0.76 and T =2.72 Sec.

Using these values (K= 0.4167, L= 0.76 and T =2.72 Sec), the PID Controller can be obtained using MATLAB function described in (Appendix A).

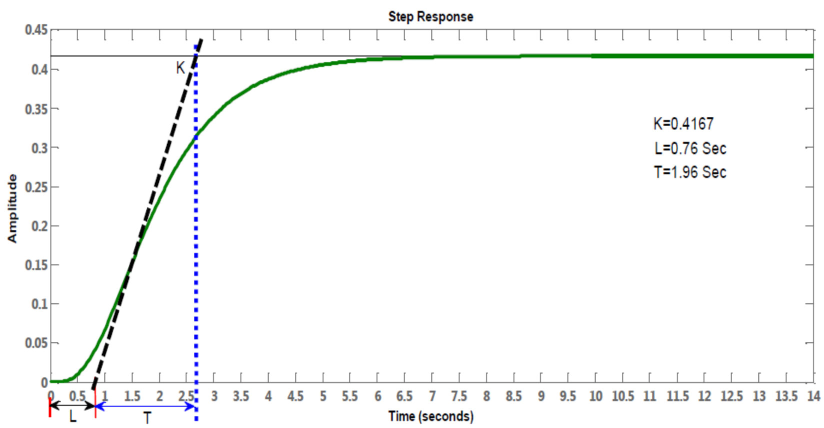


Figure 3: Finding the K, L and T from 'S' Shaped Step response Curve

There is MATLAB function **'dcgain (system)',** which can give the 'K' value of the system described in transfer function.

4.2.2 Sustained Oscillation Method

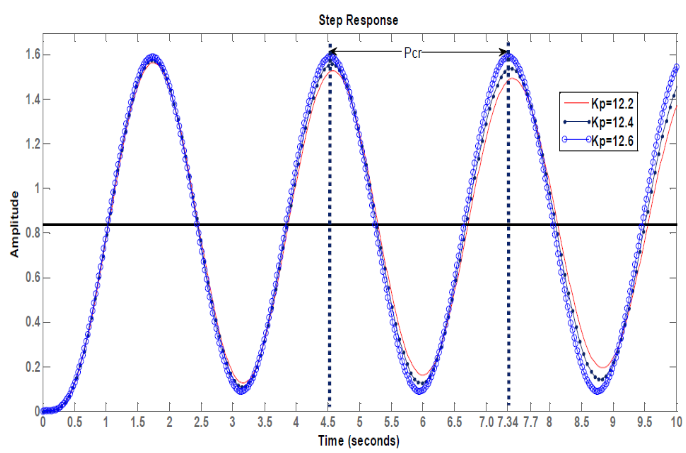


Figure 4: Obtain The Critical Gain (K_{cr}) and Period (P_{cr}) from Sustained Oscillation Curve.

Simulating the system with various valus of K_p, we obtain the above Figure 4, it can be seen that there is a sustained oscillation at K_p=12.6, hence the Critical Gain (K_{cr}) =12.6 and Period (P_{cr})=2.84 (approx.). Another way to find the

International Journal of Electrical and Electronics Engineers
Vol. No. 8, Issue No. 02, July-December 2016
ISSN (O) 2321-2055
ISSN (P) 2321-2045

values of Critical Gain (K_{cr}) and Period (P_{cr}) is use of MATLAB Command **'margin (system)'** function. However a mathematical approach can also be implemented to find the values as described in fowling section. Mathematically Calculation of Critical Gain (Kcr) and Period (Pcr).Consider the Plant in Eq.1 and P Controller as alone shown in Figure 5.

The closed loop transfer function is shown as,

$$\frac{C(s)}{Y(s)} = \left[\frac{10K_p}{S^4+10S^3+35S^2+50S+(24+K_p)}\right] \quad (4.6)$$

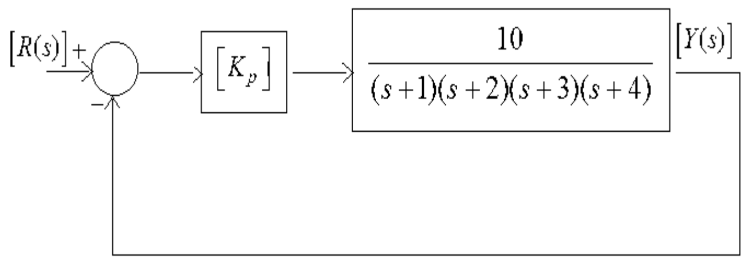


Figure 5: Mathematical Calculation of (Kcr) and (Pcr)

Using the Routh-Horwitz stability criteria, the Value of Kp, will give the marginal stability of the system by the system characteristics equation,

$$S^4+10S^3+35S^2+50S+(24+10K_p) \quad (4.7)$$

The Routh Array is shown as:

S^4	1	35	(24 + 10 Kp)
S^3	10		0
S^2	30	(24 + 10 Kp)	
S^1	(42+ 3.33 Kp)		
S^0	(24 + 10 Kp)		

From above Routh Array, the Value of Kp= 12.61, and the Value of Kcr = 12.61. Next, to find the Period of oscillation Pcr.

Substitute s = jw, in the Characteristics Eq. (4.7). We will get

(jw)4+(jw)3 + 35 (jw)2 + 50 (jw) + 24 = 0 (4.8)

As we know, Period of oscillation $P_{cr}=\frac{2\pi}{\omega}$, after solving the Eq.17, we calculate the P_{cr} = 2.23 , hence we used this Values (K_{cr} = 12.6 &P_{cr} = 2.23)to calculate the Values of PID Controller using the Table 2.

a. **Observation1:** Different Controller Response (P.PI and PID) tuned in Process reaction Curve Method

International Journal of Electrical and Electronics Engineers
Vol. No. 8, Issue No. 02, July-December 2016
ISSN (O) 2321-2055
ISSN (P) 2321-2045

(Shown in Figure 6) and Sustained Oscillation Method (Shown in Figure 7).

b. **Observation 2:** Observing the difference between the closed loop response of the systemwhen a Derivative Controller is used along the Controller and with a derivative Filter (PID tuned in Process reaction Curve Method (Figure 8) and Sustained Oscillation Method (Figure 9).

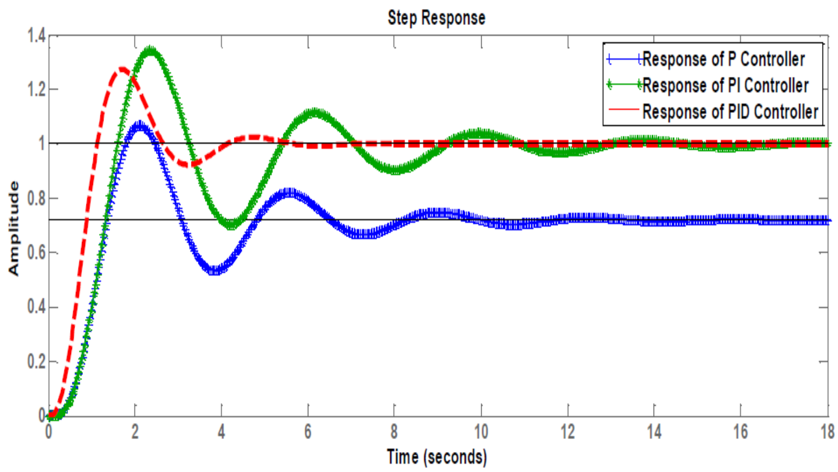


Figure 6: System Response of P,PI& PID Controller tuned with Process Reaction Curve Method

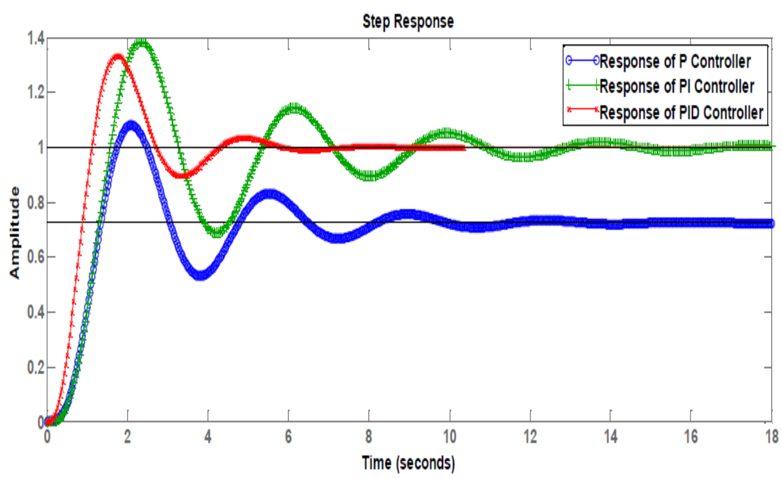
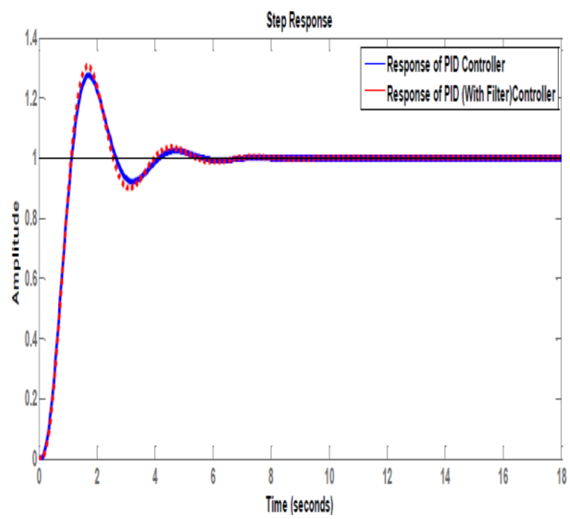


Figure 7: System Response of P,PI& PID Controller Tuned with Sustained Oscillation Method.

International Journal of Electrical and Electronics Engineers
Vol. No. 8, Issue No. 02, July-December 2016
ISSN (O) 2321-2055
ISSN (P) 2321-2045



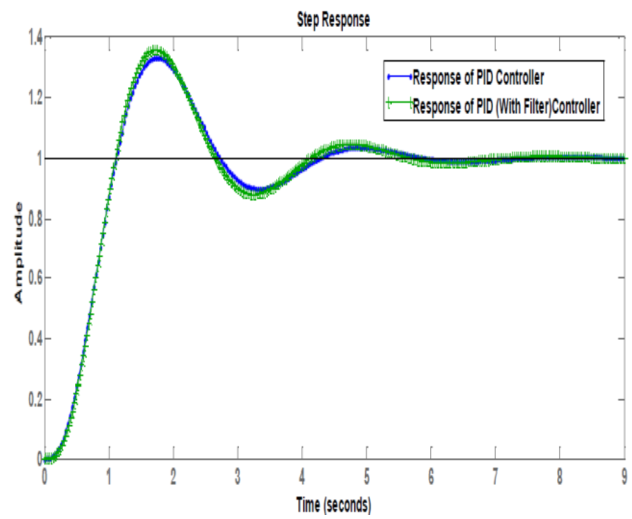


Figure 8 **Figure 9**

Figure 8: Comparison of PID and PID with Derivative Filter Controller

Figure 9: Comparison of PID and PID with Derivative Filter Controller (Sustained Oscillation Method)

V CONCLUSION

In this paper, we studied the tuning methods for PID controller using ziegler-nichols method. A fourth-order plant was taken as the control object. Numerical result was carried out using MATLAB to get the output response of the system to a step input.

In this paper is ziegler-nichols method proposed, and successfully applied to tuning for PID controller. The proposed approach is improving the system response, improve the steady state error and decrease the peak over shoot of system. The min advantage of purposed method is often used when the mathematical model of the system is not available. The Ziegler-Nichols method can be used for both closed and open loop systems.

REFERENCE

[1] M. Sahib, "A novel optimal PID plus second order derivative controller for AVR system", Eng. Sci. Technol. Int. J. Vol.18, pp. 194–206, 2015.

[2] M.J. Mahmoodabadi, H. Jahanshahi, "Multi-objective optimized fuzzy-PID controllers for fourth order nonlinear systems", Engineering Science and Technology, an International Journal, Vol. 19, pp.1084–1098, 2016.

[3] Norbert Hohenbichler. "All stabilizing PID controllers for time delay systems"; Vol. 45(11): pp.2678–84, 2009.

[4] Liang Taonian, Chen Jianjun, Lei Chuang. “Algorithm of robust stability region for interval plant with time delay using fractional order PIkDl controller”. J Commun Nonlinear SciNumer Simul Vol. 17(2), pp.979–91, 2012.

[5] Suji Prasad SJ, Varghese Susan, Balakrishnan PA. “Particle swarm optimized pid controller for second order time delayed system”. Int J Soft ComputEng; Vol. 1(2): pp. 2231–307, 2012.

[6] Rama Reddy D, Sailaja M. “Stability region analysis of PID and series leading correction PID controllers for the time delay systems”. Int J EngSciTechnol, Vol. 4(07), pp. 1-8 2012.

[7] Luo Ying, Chen Yang Quan. “Stabilizing and robust fractional order PI controller synthesis for first order plus time delay systems”. J Automatica; Vol. 48(9): pp. 2159–67, 2012.

[8] Bouallegue S, Haggege J, Ayadi M, Benrejeb M. “ID-type fuzzy logic controller tuning based on particle swarm optimization”;Vol.25 (3), pp. 484–93, 2012.

[9] Shabib G. “Implementation of a discrete fuzzy PID excitation controller for power system damping”. Ain Shams Eng J; Vol. 3(2): pp.123–31, 2012.

[10] OzbayHitay, Bonnet Catherine, Fioravanti Andre Ricardo. “PID controller design for fractional-order systems with time delays”. SystContr Lett; Vol.61(1): pp.18–23, 2012.

[11] Zhao YM, Xie WF, Tu XW. “Performance-based parameter tuning method of model-driven PID control systems”. ISA Trans, Vol.51(3): pp.393–9, 2012.

[12] Feliu-Batlle V, Rivas-Perez R, Castillo-Garcia FJ. “Fractional order controller robust to time delay variations for water distribution in an irrigation main canal pool”. Comput Electron Agric; Vol.69(2), pp.185–97, 2009.

[13] SahuRabindra Kumar, Panda Sidhartha, Rout Umesh Kumar. “DE optimized parallel 2-DOF PID controller for load frequency control of power system with governor dead-band nonlinearity”. Int J Electr Power Energy Syst; Vol.49: pp.19–33, 2013.

[14] DebbarmaSanjoy, SaikiaLalit Chandra, Sinha Nidul. “Automatic generation control using two degree of freedom fractional order PID controller”. Int J Electr Power Energy Syst; Vol.58, pp.120–9, 2014.

[15] Ziegler, J. G. and N. B. Nichols “Optimum settings for automatic controllers.” Transaction fo the ASME, Vol.64, pp. 759–768, 1942.

[16] Ogata, K., Third ed, Modern Control Engineering, Prentice-Hall Inc, 1997.

[17] K. J. Åström, T. Hägglund, “Revisiting the Ziegler-Nichols step response method for PID control”, Journal of Process Control, Vol. 14, pp. 635-650, 2004.

[18] Levine, W.S. ed., The control handbook, CRC Press, 1995.