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Design and Comparison of a Multi-Purpose PID Controller using Classical and Zeigler-Nichols Technique

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***Abstract*-PID controller tuning is designed using Matlab (Simulink). The design also gives us optimization of PID controller without too much mathematic calculations. Ziegler-Nichols closed loop method is used for the design of tuning PID controller. Some disadvantages have been found in this technique, it is time consuming method because trial and error procedure is involved. The traditional PID controller is replaced by Ziegler Nichols tuning PID controller so that is applied to wide range of processes and to obtain the minimum steady state error, also to improve the other dynamic behavior. The problem has been solved by using Matlab (Simulink) which has the ability to characterize both compensated and uncompensated relationship and we can learn this relationship from the data being modeled. These results can then be marked authorized by using Matlab (Simulink) and manual calculations. K_p, τ_i, and τ_d used in Ziegler-Nichols formula can be calculated manually.**

Keywords:* *PID controller, Ziegler-Nichols, Matlab (Simulink), (K_p) Proportional gain, (τ_i) integral time, (τ_d) derivative time.

I. INTRODUCTION

PID controllers are commonly used in the process industries for the reason of simplicity and outstanding performance. More than 95% of closed loop process use PID controllers. Control systems are designed to achieve specific objectives. For control system design some characteristics are required. A good quality control system has a lesser amount of error, excellent response, high accuracy, damping that has no unnecessary overshoot and fine stability [1]. Several tuning methods have been proposed up to now for getting more accurate and stable control response. Based on our requirement we want to characterize process dynamics by few features. Some tuning methods considered only one feature as a condition for their tuning algorithm. Some of these tuning methods considered more than one feature as a condition for their tuning algorithms [2]. In this study we will give an idea about new tuning rules in spirit of Ziegler and Nichols.

II. PID CONTROLLER

The letters P, I and D stands for P – Proportional, I – Integral and D- Derivative. Transfer function for PID controller is written as

$$G(s) = K_p + \frac{K_i}{s} + K_d s \qquad (1)$$

$$G(s) = \frac{K_d s^2 + K_p s + K_i}{s} \qquad (2)$$

Where K_p = Proportional gain, K_i = Integral gain and K_d= Derivative gain. All of these K_p, K_i and K_d are tuning parameters.

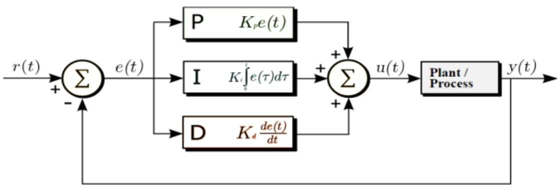

Figure 1: Block diagram of PID controller in cascade with the plant

We assume that controller in the Figure 1 is a closed-loop unity feedback system. The variable $e(t)$ represents the error which is sent to PID controller. The signal $u(t)$ is equal to the proportional gainK_p time's error signal plus the integral gain K_i time's integral of the error signal plus the derivative gain K_d times derivative of the error signal [3].

$$u(t) = K_p e(t) + K_i \int_0^t e(t)\, dt + K_d \frac{de(t)}{dt} \qquad (3)$$

III. ZIEGLER-NICHOLS CLOSED LOOP METHOD

Thismethod is a trial and error tuning based method on continuous oscillations was first proposed by John G. Ziegler and Nathaniel B. Nichols in 1942. This method is widely used for tuning PID controllers and is also recognized as continuous cycling method or ultimate gain tuning method. Ziegler and Nichols use ¼ decay ratio as a design criterion for this method.

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In the Ziegler-Nichols closed loop method First of all the system is stabilized into steady state now put on the PID controller into P controller by setting $\tau_i = \infty$ and $\tau_d = 0$ as shown in Figure 2. Increase K_p until the system oscillates continuously. Use Table 1 to get the approximate values for the controller gains K_p, K_i and K_d [4].

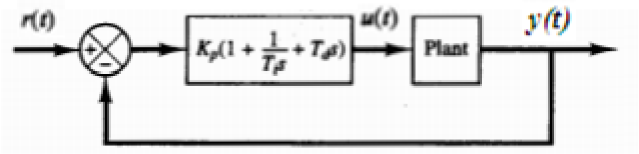

Figure 2: Closed loop system with Proportional gain (K_p)

Table 1: Controller parameter for closed loop Ziegler-Nichols method

Controller	K_p	τ_i	τ_d
P	$0.5K_{pu}$	∞	0
PI	$0.45K_{pu}$	$\frac{P_u}{1.2}$	0
PID	$0.6K_{pu}$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

The gain that gives us these continuous oscillations is ultimate gain K_{pu}, P_u is the period of oscillation at K_{pu} as shown in the Figure 3 [5].

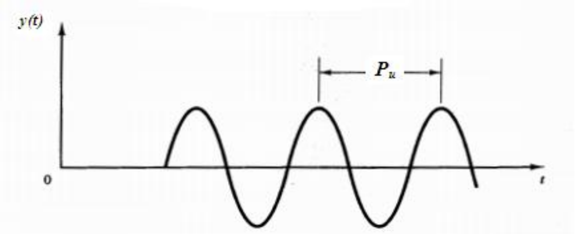

Figure 3: Sustained oscillation with period (P_u)

IV. GENERALIZED MODEL FOR PID CONTROLLER

Observe that PID controller tuned by Ziegler-Nichols closed loop method gives:

Now from Eq. (1)

$$G(s) = K_p + \frac{K_i}{s} + K_d s \quad (4)$$

Where $\tau_i = \frac{K_p}{K_i}$ and $\tau_d = \frac{K_d}{K_p}$

$$G(s) = K_p\left(1 + \frac{1}{\tau_i s} + \tau_d s\right) \quad (5)$$

Where K_p is proportional gain, τ_i is integral time and τ_d is referred as derivative time [6].

For PID-controller

$$G(s) = \frac{K_p.\tau_i.\tau_d s^2 + K_p.\tau_i s + K_p}{\tau_i s} \quad (6)$$

V. SIMULATIONS AND RESULTS

Consider the control system as shown in Figure 4 in which PID controller is used to control the system the PID controller has the transfer function.

$$G(s) = \frac{1}{(s+10)(s^2+2s+5)}$$

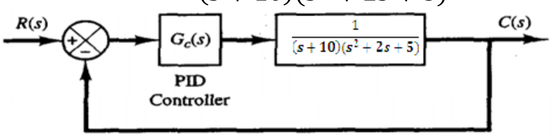

Figure 4: PID controlled system

(i). Lag-Lead compensator

$$G_1(s) = \frac{616s^2 + 1908s + 184.4}{s^5 + 27.21s^4 + 207.672s^3 + 432.07s^2 + 764.29s + 7.6}$$

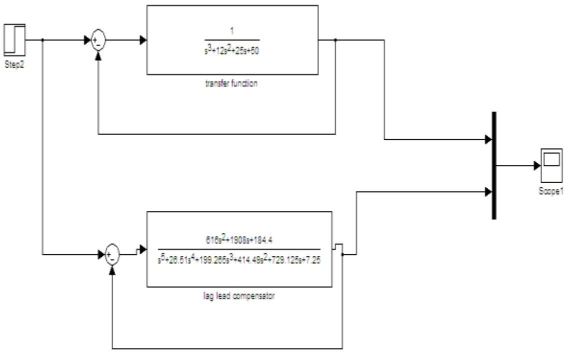

Figure 5: Simulink model of Lag- lead compensator

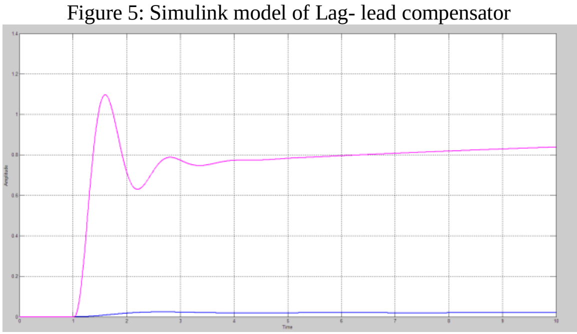

Figure 6: Lag- lead compensator response

(ii). Ziegler-Nichols closed loop method

By setting $\tau_i = \infty$ and $\tau_d = 0$ we obtain the closed loop transfer function as follows:

$$\frac{C(s)}{R(s)} = \frac{K_p}{(s+10)(s^2+2s+5) + K_p}$$

Characteristic equation for the closed loop system is;

$$s^3 + 12s^2 + 25s + (50 + K_p) = 0$$

Using Routh's stability criterion we find that continuous oscillation will occur at the ultimate gain K_{pu}.

$$K_{pu} = 250$$

$$P_u = \frac{2\pi}{\omega} = \frac{2\pi}{5} = 1.25$$

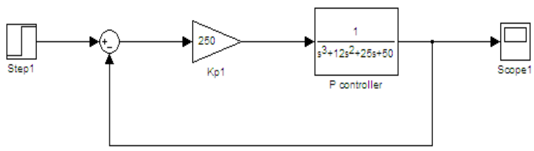

Figure 7: Simulink diagram for Sustained Oscillations

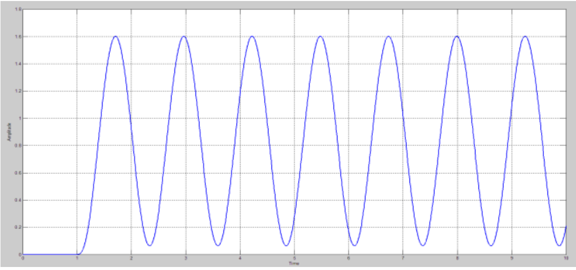

Figure 8: Sustained oscillation for $K_{pu} = 250$

From Table 1 we determine K_p, τ_i and τ_d as follows:

$$K_p = 0.6K_{pu} = 0.6 * 250 = 150$$
$$\tau_i = 0.5P_u = 0.5*1.25 = 0.625$$

$$\tau_d = 0.125\ P_u = 0.125*1.25 = 0.15625$$

Using eq. (5) we get

$$\boxed{K_p = 150}$$

$$\boxed{K_i = 240}$$

$$\boxed{K_d = 23.43}$$

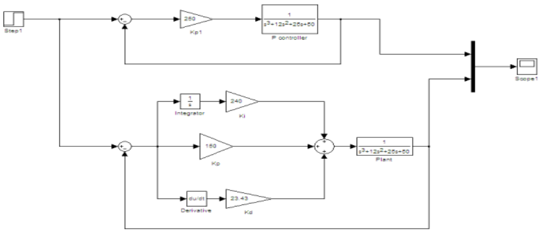

Figure 9: Simulink model of Ziegler-Nichols closed loop method

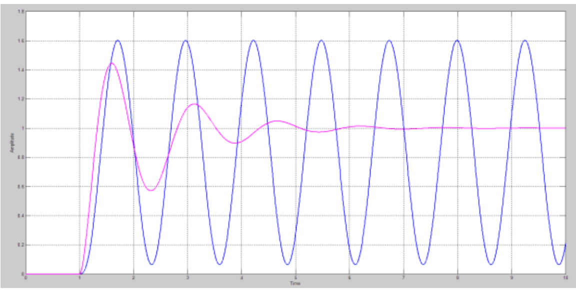

Figure 10: Ziegler-Nichols closed loop method response

(iii). Lag lead compensator and Ziegler Nichols closed loop method

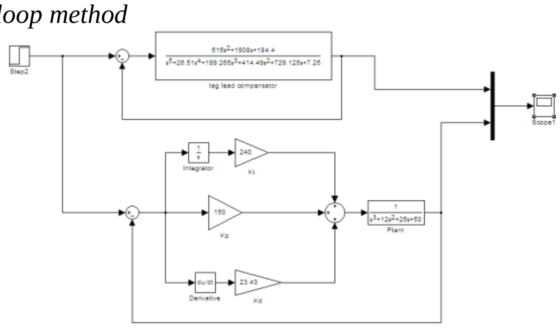

Figure 11: Simulink model of Lag-lead compensator and Ziegler-Nichols closed loop method

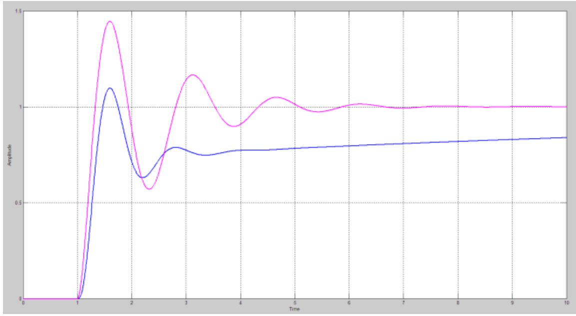

Figure 12: Lag-lead compensator and Ziegler-Nichols closed loop method responses

VI. CONCLUSIONS

In this research, comparison between classical lag-lead compensator and Ziegler-Nichols technique is applied to an under damped system. The analysis is done based on mathematical calculations and then system response is obtained from the SIMULINK. The result of simulation shows that both methods improve system performance to a desired value. System response is mainly depends on both transient response and steady state response. In classical lag-lead compensator, both transients and error is improved to a significant value. While in Ziegler-Nichols technique, steady state error is effectively improved while there is no change in transient response. Ziegler-Nichols tuning is applicable to specific applications while it is not considered as optimal. This tuning gives maximum reduction in disturbance parameter in PID loop. But the gain and overshoot is high in this technique which is acceptable in some applications. So it is concluded that both methods are applicable to tune system response as per desired values.

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