Study of Response of Various Controllers Using Ziegler-Nichols Controlling Technique

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Abstract— This paper presents control of First Order Plus Delay Time Control system for various controllers like P(Proportional controller), PI(Proportional Integral Controller), PD(Proportional Derivative Controller), PID(Proportional Integral Derivative controller).This paper compares the various parameters of these controllers by using their unit step response. The study of unit step response control of these controllers is done by using controlling technique named Ziegler-Nichols controlling method. As we know in today's world control system plays a vital role in development of various technologies that are being used by us in day-to-day life. So MATLAB simulations are carried out to take their responses.

Key words: P Controller, PI Controller, PD Controller, PID Controller, FOPDT, Z-N Controlling Method

I. INTRODUCTION

All the controllers play a vital role in control and automation industry. Even after hundreds of years these controllers are not replaced, but their tuning has been always remaining a contradictory part. Since almost every process exhibit time delay therefore tuning of these controllers was never an easy task. Delay time [1] plays an important role since it is present in every part of industrial process. We know that any control system when involves the movement of material or information it encounters time delay [2]. The presence of time-delay thus complicates the whole system. Since most physical, chemical, mechanical systems are affected by temperature, so it is most often measured quantity. There are a number of controlling techniques used to enhance the performance of controllers. Therefore, Heat exchanger model of a chemical reactor is considered for simulation of Z-N techniques In this paper, response of various controllers are studied by using Ziegler-Nichols techniques and are compared using MATLAB simulation . In the end part various results are compared qualitatively.

II. STEP RESPONSE OF CONTROLLERS

Classification of Industrial controllers:-
Industrial controllers [3] may be classified according to the control action as:-

- Proportional controllers
- Proportional Integral controllers
- Proportional Derivative controllers
- Proportional Integral Derivative controllers

Type of controller to use must be decided depending upon the nature of the plant and the operating condition, including such consideration as safety, cost, availability, reliability, accuracy, weight and size.

A. *Step Response of Controllers:*

1) *Proportional Control:*

A proportional control system [4] is a type of linear feedback control system. In the proportional control algorithm [6], the controller output is proportional to the error signal, which is the difference between the set point and the process variable. This can be mathematically expressed as

$$\mathrm{Pout} = \mathrm{Kp}.\,\mathrm{e}(\mathrm{t})$$

Where
Pout: Output of the proportional controller
Kp: Proportional gain
e(t): Instantaneous process error at time t.
e(t): $= SP - PV$
SP: Set point
PV: Process variable
With increase in Kp :

- Response speed of the system increases.
- Overshoot of the closed-loop system increases.
- Steady-state error decreases

But with high value, closed-loop system becomes unstable.

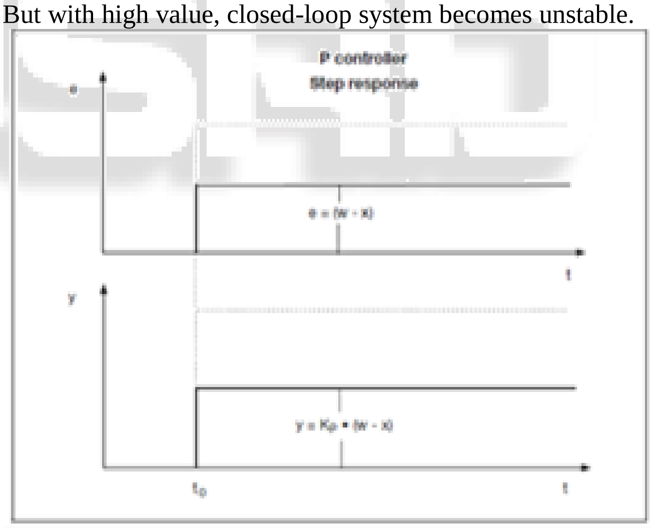

Fig. 1: Step response of P controller

2) *Proportional Integral Control:*

PI Controller (proportional + integral control) [7] is a feedback controller which drives the plant to be controlled by a weighted sum of the error (difference between the output and desired set-point) and the integral of that value. It is a special case of the PID controller in which the derivative (D) part of the error is not used..
The PI controller is mathematically denoted as:

$$\mathrm{G} = \mathrm{Kp} + \frac{\mathrm{Ki}}{\mathrm{s}}$$

Integral control action added to the proportional controller converts the original system into high order. Hence the control system may become unstable for a large value of Kp since roots of the characteristic equations may have positive real part. In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady-state error in response to various inputs.

As the value of Ti is increased:-

- Overshoot tends to be smaller and
- Speed of the response tends to be slower.

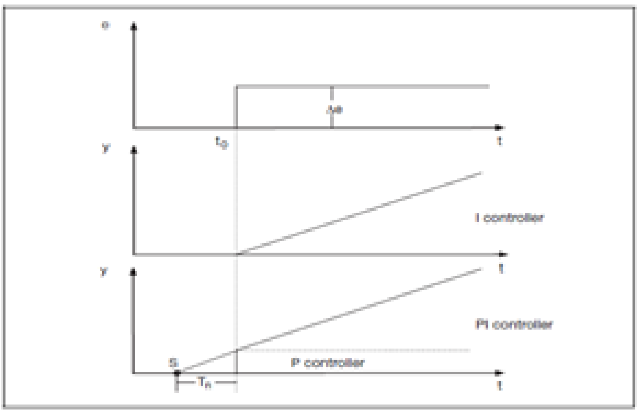

Fig. 2: Step response of PI controller

3) Proportional Derivative Control:

Proportional Derivative or (PD control [8] combines proportional control and derivative control in parallel. Derivative action acts on the derivative or rate of change of the control error. This provides a fast response, as opposed to the integral action, but cannot accommodate constant errors (i.e. the derivative of a constant, nonzero error is 0). However, derivative control will produce large control signals in response to high frequency control errors such as set point changes (step command) and measurement noise.

In order to use derivative control the transfer functions must be proper. This often requires a pole to be added to the controller.

$$\mathrm{Gpd} = \mathrm{Kp} + \mathrm{Kds} \quad \text{or}$$
$$= \mathrm{Kp}(1 + \mathrm{Tds})$$

With the increase of Td:-

- Overshoot tends to be smaller
- Slower rise time but similar settling time.

4) Prportional Integral Derivative Control:

“PID control [9]” is the method of feedback control that uses the PID controllers as the main tool. When used in this manner, the three element of PID produces outputs with the following nature:

P element: proportional to the error at the instant t, this is the “present” error.

I element: proportional to the integral of the error up to the instant t, which can be interpreted as the accumulation of the “past” error.

D element: proportional to the derivative of the error at the instant t, which can be interpreted as the prediction of the “future” error.

Thus, the PID controller can be understood as a controller that takes the present, the past, and the future of the error into consideration. The transfer function G(s) of the PID controller is

$$\mathrm{G(s)} = \mathrm{Kp}\left(1 + \frac{\mathrm{Ti}}{\mathrm{s}} + \mathrm{Tds}\right)$$
$$= \mathrm{Kp} + \frac{\mathrm{Ki}}{\mathrm{s}} + \mathrm{Kds}$$

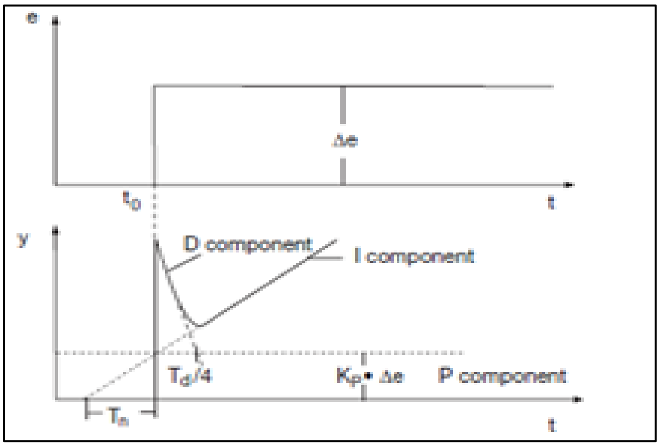

Fig. 3: Step response of PID controller

The PID controller is a simple implementation of feedback. It has the ability to eliminate steady-state offsets through integral action, and it can anticipate the future through derivative action. PID controllers, or even PI controllers, are sufficient for many control problems, particularly when process dynamics are benign and the performance requirements are modest. PID controllers are found in large numbers in all industries.

III. Delay Time

Anyone who has ever tried to stay comfortable while showering in a crowded building with old plumbing understands how delays [10] in a system can make the control problem much more difficult. If you are able design a controller that stabilizes a system containing significant delays, it will likely result in a disappointingly slow response.

Modeling Delays:

The Laplace transform for a pure delay is just:-

$$\mathrm{f(t - L)} \leftrightarrow \mathrm{e^{-sL}F(s)}$$

Where

L represents the delay time in seconds.

Thus, it’s easy to derive transfer functions for systems containing delays. For example, a system with a cascade controller and unity feedback, but using an output sensor that is τ seconds late in reporting the output.

Exponential series is given by:-

$$\mathrm{e^x} = 1 + \frac{\mathrm{x}}{1!} + \frac{\mathrm{x^2}}{2!} + \frac{\mathrm{x^3}}{3!} + \cdots,$$

And delay can be represented as:

$$\mathrm{e}^{-sL} = 1 - \frac{Ls}{1!} + \frac{\mathrm{L^2s^2}}{2!} - \frac{\mathrm{L^3s^3}}{3!} + \cdots,$$

Dead time appear in many processes in industry and in other fields, it is common in industrial process control. They are caused by some of the following phenomena:

1) The time needed to transport mass, energy or information;
2) The accumulation of time lags in a great number of low-order systems connected in series; and
3) The required processing time for sensors, such as analyzers; controllers that need some time to implement a complicated control algorithm or process (Smith O.J. 1959).

Dead times introduce an additional lag in the system phase, thereby decreasing the phase and gain margin of the transfer function making the control of these systems more difficult. For a small time delay, a PID controller is commonly used (Matausek M. R. 1996). A process plant cannot be modeled accurately. Dead time is the delay from when a controller output signal is issued until when the measured process variable first begins to respond.

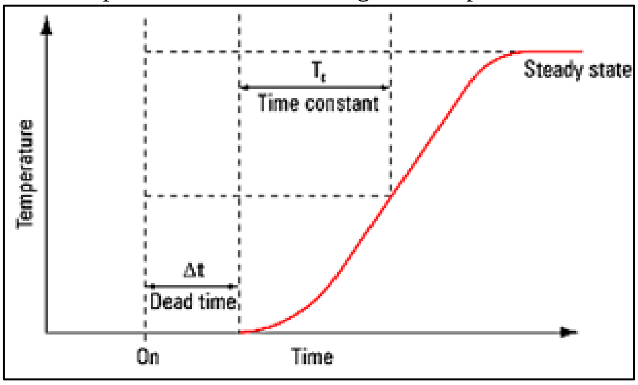

Fig. 4: Dead time response of first order transfer function

IV. System Modelling

Energy can be defined as the capacity of a body to do work. Heat transfer is an example of such process.There are three modes of heat transfer: conduction, convection and radiation

Heat exchanger is a kind of process equipment for heat exchanging .It has a wide application in industrial production and plays a very important role .For example, in the production process of refrigeration, air–conditions, chemicals, food, medicals and so on, the accurate control of the water temperature of heat exchanger outfall is not only the key to the guarantee of the production process and the quality and the output of the product, but also has an effect on energy saving. A chemical reactor called stirring tank [11] is shown below.

Heat exchanger [12] is very commonly used in chemical industry. The liquid is filled in the tank with the help of liquid inflow inlet. The valve of liquid inflow pipe is closed when the tank is filled and after that steam is passed through steam flow pipe by opening its valve. Once the liquid is heated to a desired temperature, it is taken out through the outlet valve of the stirring tank.

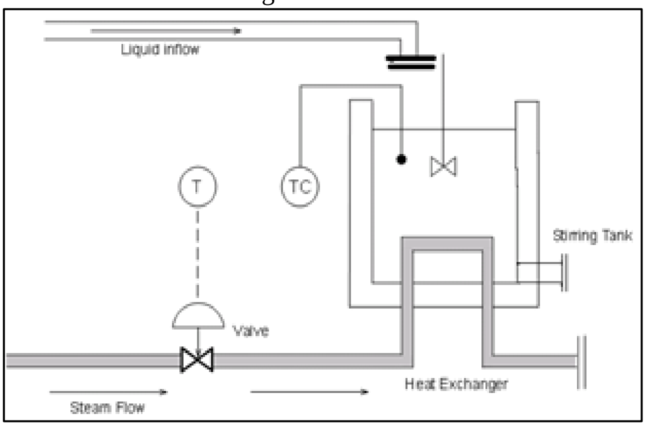

Fig. 4: Reactor with Heat Exchanger.

To derive the First order plus delay time (FOPDT) of the heat exchanger, inject a step change in valve voltage and record the temperature with respect to time

This process is shown in Figure5 with graphical representation. Different assumptions have been considered regarding this process. First assumption is that, fluid level remains constant. The second assumption is that, heat storage capacity of the insulating wall is negligible.

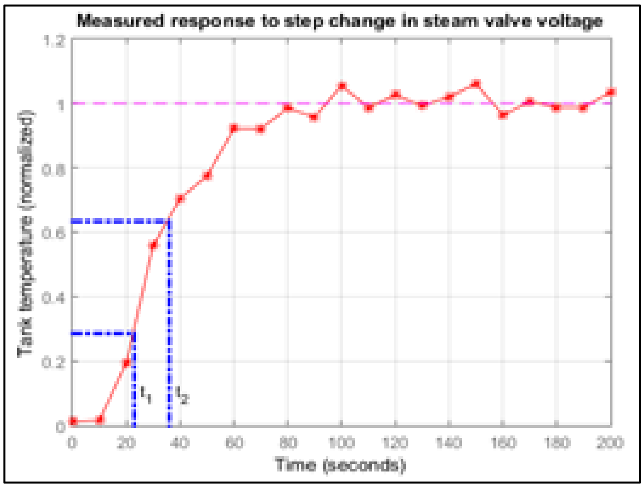

Fig. 5: Step change in steam valve voltage

From Fig.5
t1 = 21.8; t2 =36.0;
Time constant (T) = 3/2*(t2 - t1)
Time delay = t2 – T
Time constant (T) = 21.3
Time Delay (L) = 14.7
K is Gain

The transfer equation for heat exchanger is given by:-

$$M(s)=e^{-14.7s}/(21.3s+1)$$

This first order equation represents first order mathematical model of a thermal system.

V. Designing Controllers Using Z-N Method

Tuning is adjustment of control parameters to the optimum values for the desired control response. Stability is a basic requirement. However, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another. PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control.

A. *Ziegler-Nichols Open-loop method:*

The Ziegler-Nichols open loop method [13] is based on the process step response. The PID parameters are calculated from the response in the process measurement after a step signal is applied to the process. The step signal is applied to the uncontrolled process with no feedback (open loop). Perform a step test to obtain the parameters of a FOPTD (first order plus time delay) model.For First-Order plus delay time (FOPDT) model record the value of t1 and t2 at 28.3 % and 63.2 % of the above graph. By calculating as shown below one can calculate the value of “time constant”, “time delay” and static gain [14].

t1 = 21.8; t2 =36.0;
Time constant (T) = 3/2*(t2 - t1)
Time delay = t2 – T
Time constant (T) = 21.3 and Time Delay (L) = 14.7

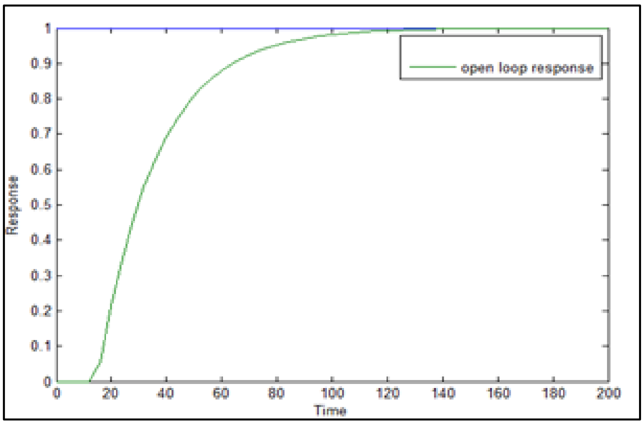

Fig. 6: Open loop response for Ziegler-Nichols method (open loop).

	Kp	Ti	Td
P	T/KL		
PI	0.9T/KL	3.3L	
PID	1.2T/KL	2L	0.5L

Table 1: Ziegler-Nichols open loop method

	Kp	Ki	Kd
P	1.44898		
PI	1.304	0.0266	
PID	1.7387	0.05914	12.779

Table 2: Ziegler-Nichols parameters for open loop method

B. Ziegler-Nichols closed loop method:

The Ziegler Nichols method [13] takes two approaches depending on the system at hand. First, with the closed method or begins in much the same way as the Trial and Error method as a steady oscillation is desired with only a proportional influence present. The proportional value at which the oscillations become constant is coined the term 'ultimate gain'. The period of oscillations at the ultimate gain is termed 'ultimate period'. The ultimate gain can be found in an simpler way with the root locus of the open loop transfer function. The ultimate gain and ultimate period as noted are applied to the Ziegler-Nichols formulae as noted in (table 3). This method works provided the closed loop transfer function is known and there is an ultimate gain, the point where the root locus value has zero for the real portion(Beniwal 2012).

To apply the Ziegler-Nichol open loop method, the output is monitored as a sharp step is applied to the input. The response is monitored for a response similar to that of figure three, which gives two of the three possible responses for an open loop system.

The third being an oscillatory system; which requires the closed approach method rather than the open loop approach of the Ziegler- Nichols methods. For this reason it is not included in the figure.

The second diagram in figure two illustrates a stable system which as the name suggests, settles to a given steady state. The last plot in the figure is an unstable system which approaches infinity due to a step applied to the input Ziegler and Nichols used the following definition of acceptable stability as a basis for their controller tuning rules: The ratio of the amplitudes of subsequent peaks in the same direction (due to a step change of the disturbance or a step change of the setpoint in the control loop) is approximately 1/4, However, there is no guaranty that the actual amplitude ratio of a given control system becomes 1/4 after tuning with one of the Ziegler and Nichols' methods, but it should not be very different from 1/4. This definition of acceptable stability implies worse stability than the definition, It has actually become common point of view that the 1/4 decay ratio of the step response, If A2/A1 ≈ 1/4 the stability of the system is ok, according to Ziegler and Nichols corresponds too poor stability of the control loop. If the stability of the control loop becomes too poor, try to adjust the controller parameters. The first aid, which may be the only adjustment needed, is to decrease Kp somewhat, for example a 20% decrease. It is also important to remember the impact of the measurement noise on the control signal. The more aggressive controller, fast control, the more sensitive is the control signal to the measurement noise. Again, to decreases this sensitivity, the controller gain can be decreased. Note that the Ziegler-Nichols' closed loop method can be applied only to processes having a time delay or having dynamics of order higher than 3(Copeland & Rattan 1994).

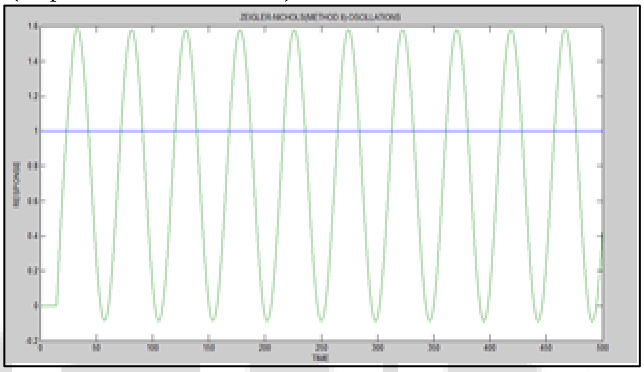
Fig. 7: Ziegler-Nichols frequency response test.

Step I: Find out the sign of process gain.
Step II: Introduce proportional control.
Step III: Raise proportional gain until sustained periodic oscillation occurs.
Step IV:Note down ultimate gain Ku (gain at which oscillation occurs) and Ultimate period Pu (distance between two consecutive crests.)
Step V: Calculate control parameters as prescribed by Ziegler and Nichols.

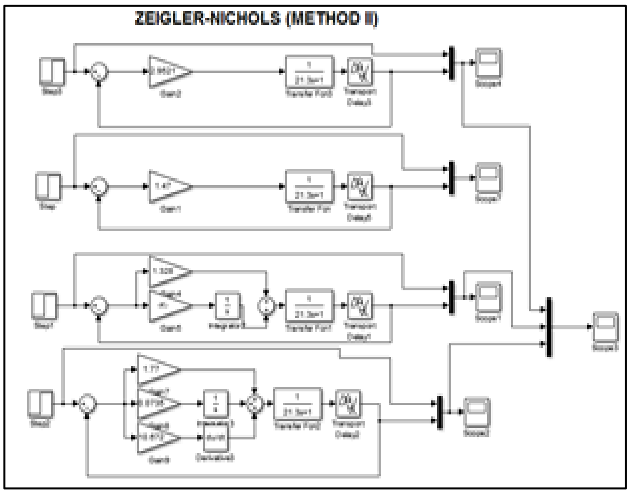

Fig. 8: Simulink Model Zeigler Nichols Close Loop Method

	Kc	Ti	Td
P	Ku/2		
PI	Ku/2.2	Pu/1.2	
PID	Ku/1.7	Pu/2	Pu/8

Table 3: Ziegler Nichols close loop PID controller

	Kp	Ki	Kd
P	1.47		
PI	1.328	0.05512	
PID	1.77	0.0735	10.672

Table 4: Ziegler Nichols parameters for close loop PID controller

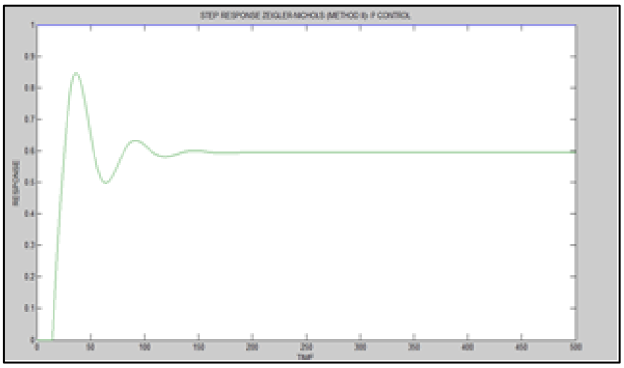

Fig. 9: Response with P controller (Ziegler-Nichols method)

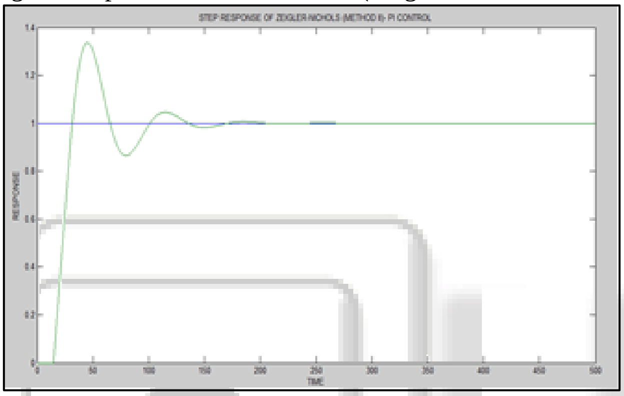

Fig. 10: Response with PI controller (Ziegler-Nichols method)

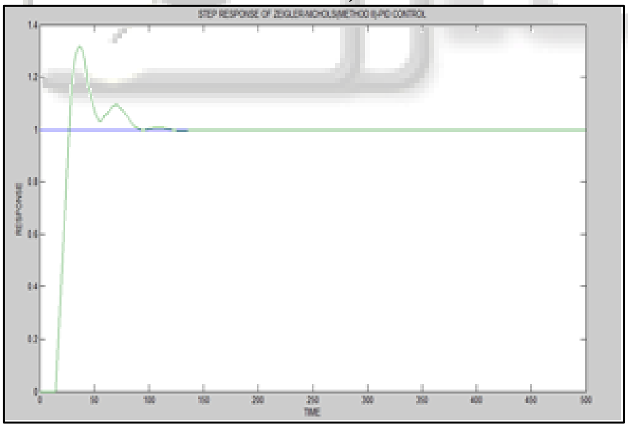

Fig. 11: Response with PID controller (Ziegler-Nichols method)

	Peak Amplitude	Overshoot	Settling Time (In Sec)	Rise Time (In Sec)
Z-N(Open-Loop)	1.1583	15.8 %	111	10.65
Z-N(Closed-Loop)	1.31	31.6%	85.32	9.91

Table 5: Comparison of Z-N methodology for PID Controller

	Peak Amplitude	Overshoot	Settling Time (In Sec)	Rise Time (In Sec)
Z-N(Open-Loop)	1.017	1.7	208.5	17
Z-N(Closed-Loop)	1.336	33.6%	150	13.30

Table 6: Comparison of Z-N methodology for PI Controller

VI. CONCLUSION

In this paper the response of First Order Plus Delay Time System is compared for various controllers for Z-N open loop and closed loop method. Among all controllers PID controller is most commonly using control strategy with Z-N control strategy with good response and controlled overshoot where as PI controller is having high settling time. Therefore, we can choose controller according to our need.

REFERENCES

[1] Yingjian Xu, Dept. of Automation, Shanghai Jiao Tong Univ., Shanghai, China; A simple PID controller tuning strategy for first order plus dead time model electronics, Communications and Control(ICECC), 2011.
[2] Andri Mirzal, "Stability Analysis and Compensation of Time Delays in Analog Control Systems" International Journal of Control and Automation Vol. 5, No. 4, December, 2012
[3] Manfred Schleicher, Frank Blasinger, Control Engineering 3rd edition, Book Number: FAS 525
[4] Ann M. Simon, "A Comparison of Proportional Control Methods for Pattern Recognition Control, Engineering in Medicine and Biology Society.", EMBC, 2011, Annual International Conference of the IEEE on Aug. 30 2011- Sept. 3 2011, Page(s):3354 – 3357, Boston, MA
[5] "Tuning of Optimal and Robust PID Controller for Open-Loop Unstable First-Order plus Time Delay Systems", Control Conference (CCC), 2012 on 25-27 July 2012, Page(s):2459 – 2464, Hefei
[6] Yuan-Jay Wang, "Analytical Robust Tuning of PI Controllers for First-Order-Plus-Dead-Time Processes.", Emerging Technologies and Factory Automation, 2008.ETFA 2008.IEEE International Conference on 15-18 Sept. 2008 Page(s):273 – 280, Hamburg.
[7] Oytun Eris, " A new PI tuning rule for first order plus dead time system.", AFRICON, 2011 on 13-15 Sept. 2011, Page(s):1 – 4, Livingstone
[8] Hong Sheng, " FOPD Controller tuning algorithm.", Control and decision Conference, 2008. CCDC 2008 on 2-4 July 2008, Page(s):4059 – 4063, Yantai, Shandong
[9] Vila Nova, " PID Controller Tuning Rules for Robust step response of First-Order-Plus-Dead-Time models.", American Control Conference, 2006 on 14-16 June 2006, Minneapolis, MN
[10] Control of Processes with Time Delays, Industry Applications, IEEE Transactions on (Volume: 24, Issue: 2), 06 August 2002 Issue Date: Mar/Apr 1988
[11] Ramon Vilanova, "Composable Thermal Modeling and Characterization for Fast Temperature Estimation.",

Electrical Performance of Electronic Packagingand Systems,(EPEPS), 2010 IEEE 19th Conference on 25-27 Oct. 2010 Page(s):185 – 188, Austin, TX

[12] Control of Processes with Time Delays, Industry Applications, IEEE Transactions on (Volume: 24, Issue: 2), 06 August 2002 Issue Date: Mar/Apr 1988

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

[14] Mohammad Shahrokhi and Alireza Zomorrodi, "Comparison of PID Controller Tuning Methods" Department of Chemical & Petroleum Engineering Sharif University of Technology

