# Temperature Control Response Using Fuzzy PI+PID Controller

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*Abstract*—**The aim of this project is to evaluate the process performance of temperature control process using combination of Fuzzy PI and PID. In this work, the experimental data is used to determine the process model and the control analysis is done using LabVIEW software. The PID control was tune by using Ziegler-Nichols method and the Fuzzy PI controller are design with different sets of membership function. The performance of the output response is evaluated and compared in term of settling time, rise time and percent overshoot. The result had shown that the performance with 7 membership function gives better performance for temperature control process.**

***Keywords:;Fuzzy Logic Controller;Tuning method; Ziegler-Nichols***

## I. INTRODUCTION

Temperature is definitely an essential parameter within the listing of industrial control objectives. Temperature control objects have nonlinearity, strong coupling, time varying delay and other characteristics [1].how to enhance the accuracy of temperature control system has been an importance subject in the turf of industry temperature control [2].

Process control states to the actions of ensuring a process is stable and continuously operating at a desired temperature by controlling the temperature of energy from the source to the output device. One of the vital parts in a process control is the controller, it acting a big role in term of producing and maintaining the desired output [3]. Proportional integral derivative (PID) controller is the popular controller used in a process industries.

PID controller is actually controllers which have an easy to understand, easy to design, and low-cost operation and is very appropriate to be applied in the process industry, Due to these types of requirements, the PID continues to be suitable as well as relevant even today. Because of the PID is still use until now in the industry, uses of PID must be enhanced through giving an increasing productivity technique to tune the PID parameters [4].

Nowadays, the industrial plants clearly present high order with time delays, and nonlinearities [4]. Reported that the PID control work perfect in linear system, to increase the performance of the controller, PID controller and fuzzy controller may be combine to get the benefit of both.

The objective of this project is to compare and evaluate the temperature control performance using combination Fuzzy-PI and PID controller. The performance response of the temperature control process is evaluated based on percent overshoot, rise time and settling time to show the best performance response for this study.

## II. THEORY

### A. *Process Model*

Basically, the first order plus dead time model (FOPDT) is as shown in Eqn. (1) where Tp is the process constant time and Kp is the process gain.

$$G(s) = \frac{Kpe^{-to\,s}}{Tp\,(s)+1} \qquad \ldots (1)$$

In this work, the process parameters are obtained using two-point method. This method is an analytical method that used by measure the reaction graph as shown in Fig. 1.

$$Kp = \frac{Yfinal - Yinitial}{Ufinal - Uinitial} = \frac{\Delta Y}{\Delta U} \qquad \ldots (2)$$

$$Tp = \frac{3}{2}(t1 - t2) \qquad \ldots (3)$$

$$to = t2 - Tp \qquad \ldots (4)$$

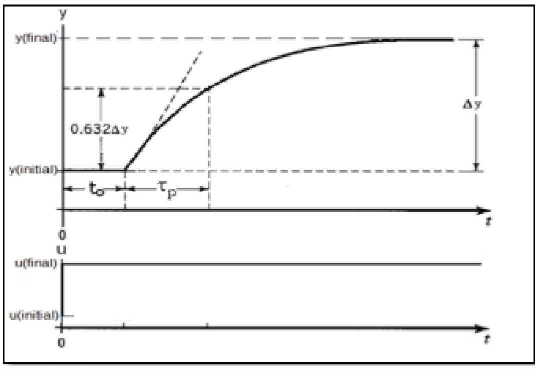

Fig. 1: Estimation of First-Order model process response using two point method [3].

### B. *PID Controller*

PID interpreted in terms of time where, 'P' depends on the present error, 'I' on the accumulation of past errors and 'D' is a prediction of future errors, based on current rate of change [6].

A PID controller determines an error value in term of difference between a desired set point and measured process variable based on proportional, integral, and derivative terms. The controller tries to reduce the error over time by setting the control variable. The ideal PID algorithm is as shown in Eqn. (5) where u is the control signal, $e$ is error, $K_p$ is the proportional gain, $T_i$ is the integral time, and $T_d$ is the derivative time [3] .

$$u(t) = Kp(e(t) + \frac{1}{Ti}\int_0^t e(t)d(t) + Td\frac{de(t)}{d(t)}) \quad \ldots (5)$$

The Ziegler-Nichols methods is one of common methods used in process control to determine the parameters of a PID controller [7]. Ziegler-Nichols proposed rules for decide the values of the proportional gain Kp, integral time Ki and derivative time Kd based on the transient–response characteristics [8]. In this tuning method, the controller gains can be calculated as shown in Table I.

TABLE I. Ziegler-Nichols tuning rule

| Controller Type | Proportional Gain ($K_c$) | Integral Time ($T_I$) | Derivative Time ($T_D$) |
|---|---|---|---|
| P-only | $\frac{1}{K_p}\left(\frac{\tau_p}{t_0}\right)$ | - | - |
| PI | $\frac{0.9}{K_p}\left(\frac{\tau_p}{t_0}\right)$ | $3.33t_0$ | - |
| PID | $\frac{1.2}{K_p}\left(\frac{\tau_p}{t_0}\right)$ | $2t_0$ | $0.5t_0$ |

The terms $t_o$ and $T_p$ in the formulae represent the time delay and time constant of the process respectively. The temperature process is represented using first order plus dead time (FOPDT) model as shown in Eqn. (6) [9].

$$Gp(s) = \frac{ke^{-to}}{Tp+1} \quad \ldots (6)$$

### C. *Fuzzy Logic Controller (FLC)*

The implementation of Fuzzy Logic Controller in the process control is not new [10]. Fuzzy controller is a fuzzy logic based controller which consist of four main part which is fuzzification, interface mechanism, rule base and defuzzification. A block diagram is shown in Fig. 2 [11].

Based on the block diagram in Fig. 2 rule base is a set of fuzzy rules of the type "if-then" which use fuzzy logic to quantify the expert's linguistic descriptions regarding how to control the plant. Inference mechanism emulates the expert's decision-making process by interpreting and applying existing knowledge to determine the best control to apply in a given situation. Fuzzification is a process of matching the input variable of the controller to a rule base linguistic form system. Interface mechanism consists of a set of linguistic control rules and employment rules to infer fuzzy control actions in response to fuzzified inputs [9].

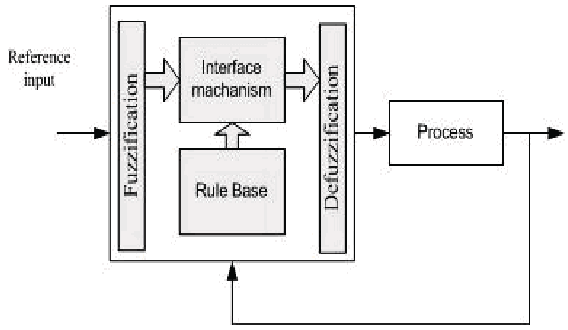


Fig. 2: FLC block diagram

Fuzzification interface converts the controller inputs into fuzzy information that the inference process can easily use to activate and trigger the corresponding rules [12]. Defuzzification is the process of converting the result reaches from the fuzzy set to the output controller value base on the universe of discourse output membership function.

A fuzzy logic controller is normally built from the experience of the process control or operational engineer to determine the parameters and rules of the process. Membership function is the first step to determine the range of each process. For example, Low, Medium and High. Fuzzy rule will determine what will be the output when the two or more inputs for membership functions combine. In example, if the first input is Low and the second input is Medium, so the user will determine what will be the result for the output. Both membership functions and fuzzy rule related to each other in order to get the stable output response for the process.

## III. METHODOLOGY

In this work, the process model obtained is as shown in Eqn. (7).

$$Gp(s) = \frac{1.47e^{-90s}}{1140s+1} \quad \ldots (7)$$

The Ziegler-nichols tuning method was used to tune the controller parameters and the result was observed.

The application of Fuzzy PI+PID is a combination of Fuzzy Logic and PID controllers which are proportional, integral and derivative controller. The block diagram of the

Fuzzy PI+PID application for temperature control process is as shown in Fig. 3 [9].

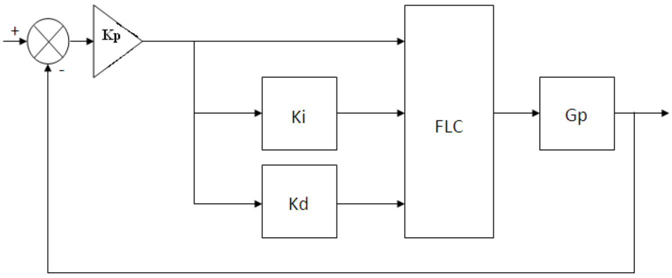


Fig. 3: Fuzzy PI+PID block diagram

This Fuzzy PI controller is designed using two input membership function which is Error (E) and Change of Error (CE). For this study, 3, 5, 7 membership functions were used and the control performance was evaluated.

## IV. RESULT AND DISCUSSION

In the result and discussion, the result for the Ziegler-Nichols tuning method which is without fuzzy, Fuzzy PI+PID for 3 membership functions and 5 membership functions and 7 membership function were compared to determine which method is more suitable to use in the temperature control of this project. All the experiments have been done by using LabView software and the parameter result using Matlab software.

Firstly, for the Ziegler-Nichols tuning method, the value of *Kp, Ki* and *Kd* must to be calculated. The gain values were stated in Table II.

TABLE II.
Gains values for Ziegler-Nichols method

| Gain | | |
|---|---|---|
| Kp | Ki | Kd |
| 1.75 | 0.0006 | 45 |

The formula for Ziegler-Nichols quite easier than the other method for the process control. The output response is shown in Fig. 4 where it able to reach the stable response.

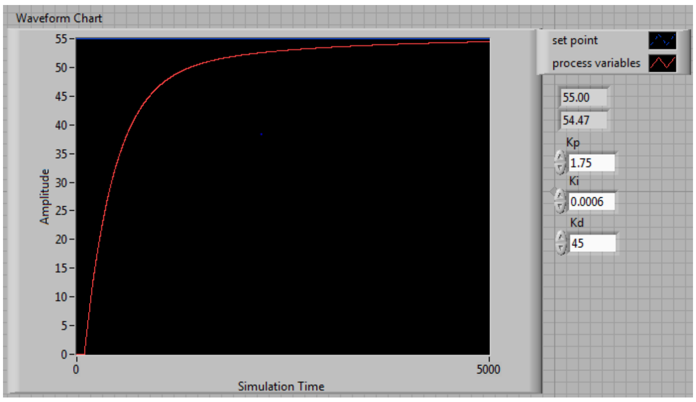


Fig. 4: Output response for Ziegler-Nichols tuning method

As shown in the Fig. 4, it proved to be the best choice for the tuning method. However, if combine to the fuzzy method, this is where the research been done to determine the best result for the temperature control. At first look, fuzzy PI+PID looks really complicated to be done. The connection to build a correct block diagram was not easy and takes long time. Besides, the appropriate memberships need to be done by using “trial and error” method which it needs to be implemented in determining the fuzzy rule as well. *Kp* is the proportional of the controller while *Kd* is derivative and *Ki* is integral controller.

Table III shows the fuzzy rule for 3 membership function of the controller where NE is Negative, ZE is Zero and PO is positive.

TABLE III.
Fuzzy Pi+Pid Control Rule For 3 Membership Functions

| E<br>CE | NE | ZE | PO |
|---|---|---|---|
| NE | NE | ZE | ZE |
| ZE | NE | ZE | PO |
| PO | ZE | ZE | PO |

The rule and the membership functions related to each other and it need to be decided based on the user according to their logic and multiple trials are needed to get the stable output waveform. As a result, Fig. 5 shows the more stable waveform if compare to the Ziegler-Nichols tuning method.

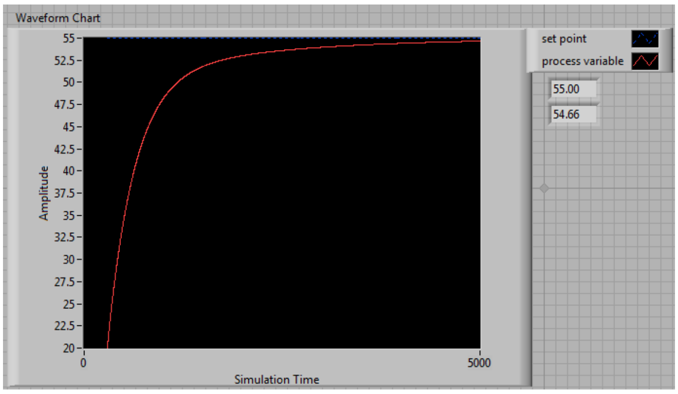


Fig. 5: Output response for Fuzzy PI+PID method for 3 membership function

As shown in Fig. 5, it shows that the percentage overshoot is approximately to zero and higher rise time as compare to Ziegler-Nichols tuning method without fuzzy. Next, was to determine if more membership functions will result the better output response for the process

Table IV shows the fuzzy rule of the controller where NB is Negative Big, NS is Negative Small, ZE is Zero, PS is Positive Small and PB is Positive Big.

TABLE IV.
Fuzzy PI+PID control rule for 5 membership functions

| E / CE | NB | NS | ZE | PS | PB |
|---|---|---|---|---|---|
| NB | NB | NS | NS | PS | PB |
| NS | NB | NS | ZE | ZE | PB |
| ZE | NB | NS | ZE | PS | PB |
| PS | NB | ZE | ZE | PS | PB |
| PB | NB | ZE | PS | PS | PB |

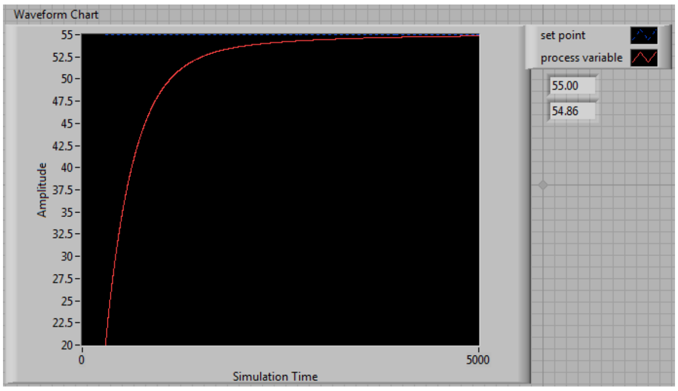


Fig. 6: Output response for Fuzzy PI+PID method for 5 membership function

As shown in Fig. 6, the result looks membership 5 is a better response than membership 3 from Fig. 5. Fig. 7, 8, and 9 shows the inputs and output membership functions 7.

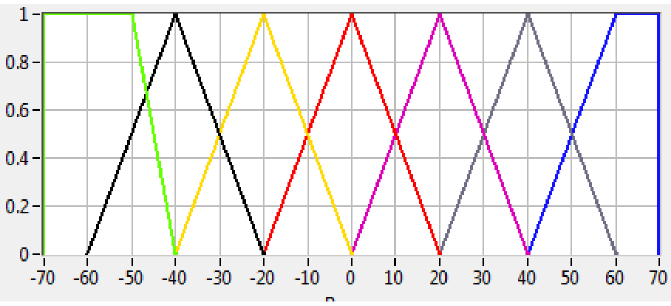


Fig. 7: Input membership function for E

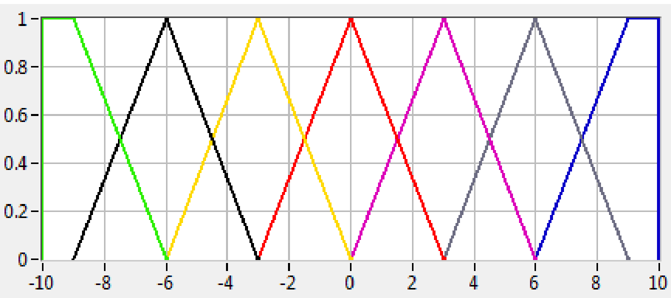


Fig. 8: Input membership function for CE

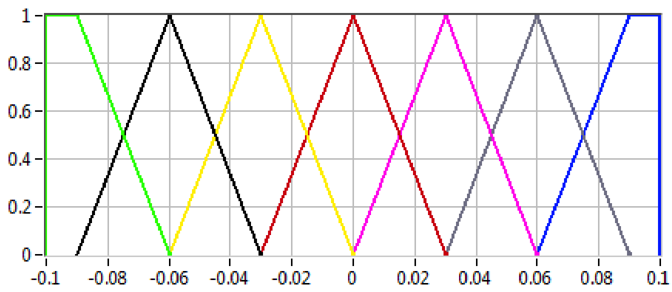


Fig. 9: Input membership function for PID

The ranges of the membership were determined by using trial and error method to get the best output response. It is not like tuning method which the value fixed according to the formula given. Table V shows the fuzzy rule of the controller where NB is Negative Big, VS is Very Small, S is Small, M is Medium, L is Large, VL is Very Large and H is High. This indicates a rule for each range based on the membership range where NB is for green color, VS is for black color, and S is for yellow color, M is for red color, L is for purple color, HL is for gray color and H is for blue color.

TABLE V.
Fuzzy PI+PID control rule for 7 membership function

| E / CE | NB | VS | S | M | L | HL | H |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | VS | S | VL | VL | H |
| VS | NB | NB | VS | M | L | L | H |
| S | NB | VS | S | M | L | L | H |
| M | NB | S | L | L | L | L | H |
| L | NB | S | S | M | L | VL | H |
| HL | NB | S | S | M | VL | H | H |
| H | NB | VS | VS | S | VL | H | H |

As shown in Fig. 10, the response for membership 7 is a better response than membership 3 and 5 from Fig. 6 and Fig. 12.

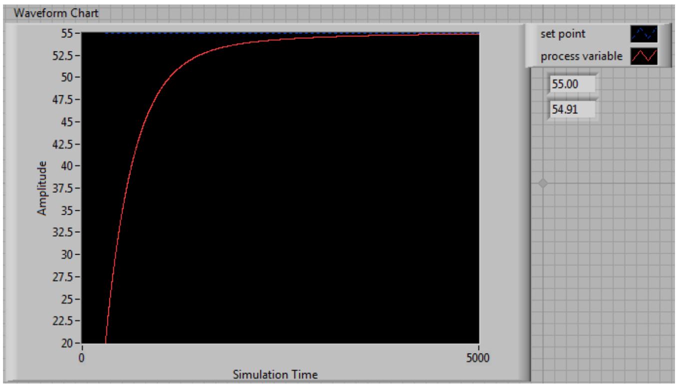


Fig. 10: Output response for Fuzzy PI+PID method for 7 membership function

TABLE VI.
Results of the waveform

| Type of Controller | Rise Time (s) | Settling Time (s) |
|---|---|---|
| Ziegler-Nichols Tuning | 1986.3 | 5103.6 |
| Fuzzy PI+PID 3 Membership | 2220.0 | 4940.3 |
| Fuzzy PI+PID 5 Membership | 2194.8 | 4845.9 |
| Fuzzy PI+PID 7 Membership | 1955.1 | 4563.2 |

Table VI shows the accurate result of the rise time and settling time for all the method to clearly prove which method is the best for controlling the temperature process.

## V. CONCLUSION

Fuzzy PI+PID for the temperature control process were successfully simulated and analyzed. The results of the methods for both 3, 5 and 7 membership functions were compared with a conventional controller, without fuzzy which is the Ziegler-Nichols tuning method. From the results, it was proven that by implementing Fuzzy PI+PID, the result would be much better and stable. Although to find the output required a lot of times, but the output response varies, where the stability of the waveform can be increased to achieve the desired given setting. Unlike the tuning method, it was easy to just calculate the value for gains by using the given formula, but the output cannot be changed and that will be the final result. So, Fuzzy PI+PID for 7 membership functions were proved to be the best choice for controlling the temperature process control.

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