Performance Evaluation for SE113 Flow Control System Plant Using Self-Tuning Fuzzy PI Controller

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***Abstract*—The aim of this project is to evaluate the process performance of SE113 Flow Control System Plant using self-tuning Fuzzy PI controller. The experimental data is used to model the process and the control analysis is done using Matlab Simulink. The performance evaluation is based on the percent overshoot, rise time and settling time of the process. The overall performance is compared with the conventional Proportional-Integral control method. The results had shown that self-tuning Fuzzy PI controller simplify the tediousness in tuning the controller and enhance the capability of PI controller-only.**

Keywords; Fuzzy PI controller, Proportional-Integral control, Matlab Simulink.

I. INTRODUCTION

Process control refers to the actions of ensuring a process is stable and constantly operating at a desired level by controlling the flow of energy from the source to the output device. One of the important parts in a process control is the controller, it plays a big role in term of producing and maintaining the desired output. One of the conventional controllers used in the process industries is PI controller. It is widely used because of its simplicity and can be used in an extensive range of operation [1]. PI uses the combination of P and I combination to produce the best output.

On the other hand, Fuzzy logic controller is an intelligent controller, which mimicking the logical human thinking base on the sets of rules and mathematical model of process [2]. Fuzzy logic controllers have the advantage of dealing with nonlinear control system and use the human operator knowledge [3]. Both of the controller have their own advantages and disadvantages. Therefore, the control strategy of combining fuzzy controller and the traditional PID controller will produce a system with better performance [4] [3] [5] [5] [6].

There is a lot of research that implements the use of the combination of Fuzzy logic control and traditional PID controllers [6] [7] [8] [9]. Fuzzy logic has appeared as powerful tools to control feedback system. In numerous of researches [10] [11] [12], Fuzzy logic is defined as a powerful tool to gain tuning in comparison to the conventional tuning method.

The objective of this project is to demonstrate the implementation of a combination of the self-tuning Fuzzy and PI controller on the SE113 Flow Control System Plant. The project is focused on the closed loop performance by using Ziegler-Nichols tuning method for experimental process model. The dynamic performance of the process is evaluated in terms of percent overshoot, rise time and settling time. In addition to that, process response of PI controller is used for dynamic process performance comparison.

II. SYSTEM DESCRIPTION

The process plant shown in Figure 1 is a system located at DCS laboratory, UiTM Shah Alam used for water flow control system and measurement. The process plant is equipped with the vortex flow meter and integral orifice differential pressure transmitter for water flow measurement.

Figure 1. SE113 Water flow control system plant

The available process plant is designed for a single loop water flow control system. The water is pumped through pump P-520, passing through an orifice differential pressure transmitter, FT-520 back to the sump tank. The signal from the orifice transmitter is used to feed the controller, which will then transmit a signal to the control valve, FCV-520 for the required opening as water is being pumped back to the sump tank. The water flow control is as illustrated in Figure 2.

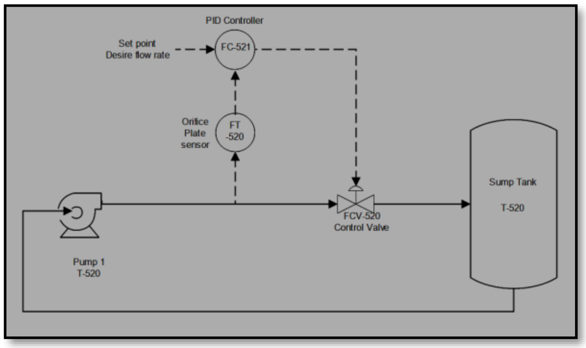

Figure 2. SE113 Water flow control schematic diagram

III. METHODOLOGY

The flow chart of this project is shown in Figure 3. This project has two parts, which is the experimental and simulation work.

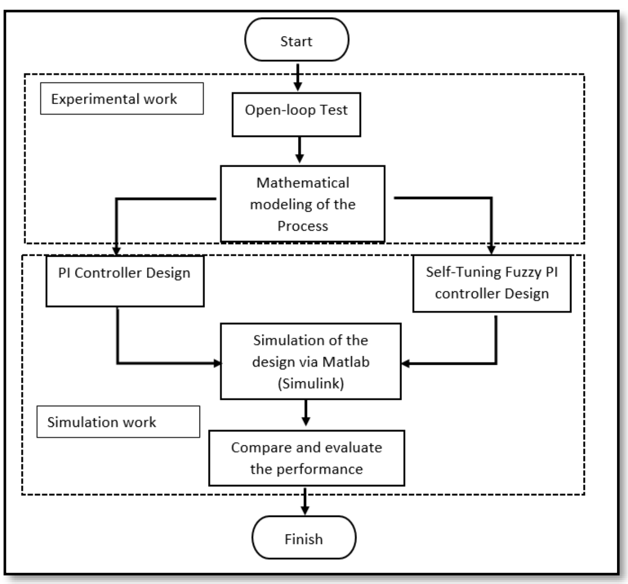

Figure 3. Flow chart of the project

In this work, an open loop step test is carried out in order to determine the process model. The experimental work is conducted using the following settings:

- The sump tank is filled with water 80% full
- The instrument air regulator set to 20psig
- Start the pump P-520
- Set the set point at 30 LPM

The controller is set to manual mode and the input change was made on manipulated variable (ΔMV) by 5%, 10%, and 15% to the controller output. Once the process reaches a new steady state level, the response curve is recorded.

In simulation work, a combination of the self-tuning Fuzzy and PI controller is designed, which the controller parameters are adjusted using Ziegler-Nichols tuning method. In this work, Matlab Simulink is used to simulate the process dynamic response.

IV. PROCESS MODEL

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

$$G(s) = \frac{K_p e^{-t_o S}}{\tau_p S + 1} \tag{1}$$

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 Figure 4.

$$K_p = \frac{y_{final} - y_{initial}}{u_{final} - u_{initial}} = \frac{\Delta y}{\Delta u} \tag{2}$$

$$\tau_p = \frac{3}{2}(t_1 - t_2) \tag{3}$$

$$t_0 = t_2 - \tau_p \tag{4}$$

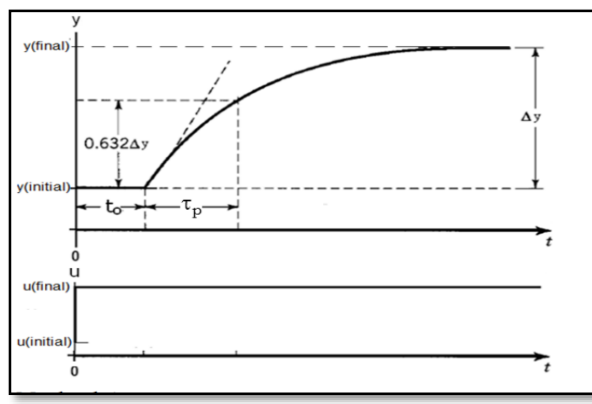

Figure 4. Estimation of process response using two point method [13].

V. PI CONTROLLER & TUNING

The conventional PI controller expression is shown in (5).

$$\mathrm{CO} = K_c\left[e(t) + \frac{1}{T_I}\int_0^t e(t)dt\right] + \mathrm{CO_{Bias}} \tag{5}$$

Where:

CO_{Bias} = controller bias or null value (the output of the controller at zero error)

K_c = controller gain, tuning parameter

T_i =integral time(also callers reset time)

e(t) = controller error = SP – PV

SP = set point

PV = measured process variable

Tuning of the PI controller parameters was done by using Ziegler-Nicholes method in which the parameters are calculated using equations shown in (6), (7) and (8).

- *Propotional gain(K_c)*

$$K_c = \frac{0.9}{K_p}\left(\frac{\tau_p}{t_o}\right) \qquad (6)$$

- *Integral Gain(K_i)*

$$T_i = 3.33t_0 \qquad (7)$$

$$K_i = \frac{K_c}{T_i} \qquad (8)$$

VI. SELF TUNING FUZZY PI CONTROLLER

The basic configuration of the Fuzzy Logic system considered in this project is as shown in Figure 5.

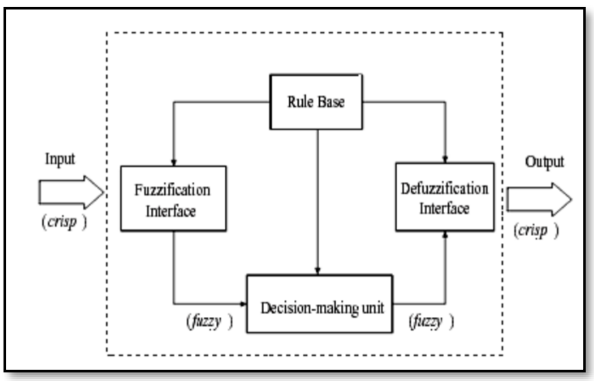

Figure 5. Basic configuration of Fuzzy Logic system

The important part that contributes to the successful operation of the Fuzzy controller is the Fuzzy control rule that is used for decision making.

The control rules used in this project are as shown in Table I and Table II.

TABLE I. KP FUZZY CONTROL RULE

E \ CE	NB	NS	ZO	PS	PB
NB	PB	PB	PS	ZO	ZO
NS	PS	PB	PS	ZO	NS
ZO	PS	PS	ZO	NS	NB
PS	PS	ZO	NS	NS	NB
PB	ZO	ZO	NS	NB	NB

TABLE II. KI FUZZY CONTROL RULE

E \ CE	NB	NS	ZO	PS	PB
NB	PS	NS	ZB	NS	PS
NS	PS	NS	NS	NS	ZO
ZO	ZO	NS	NS	NS	ZO
PS	PB	NS	PS	PS	PB
PB	PB	PS	PS	PS	PB

Figure 6 shows a self-tuning Fuzzy PI controller. In this work, the two parameters of PI controller, which denoted as K_p, and K_i is maintained [14] [15]. The two inputs of the Fuzzy logic controller are absolute error, e(t) and absolute derivative error de(t)/dt whereas, the two outputs are K_p and K_i [16].

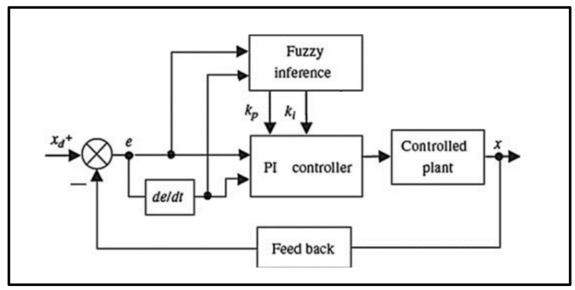

Figure 6. Self-tuning Fuzzy PI controller

Self-tuning Fuzzy PI controller is an adaptive system in accordance with the desired response. Upon the changes in desired value happened, the Fuzzy logic controller read the error signal (e(t)) and the change of error(de(t)/dt) to find the new PI parameters. It uses the error signal e(t) to generate proportional and integral action, with the resulting signals weighted and summed to form the PI controller [12].

The membership function used by the Fuzzy controller is triangular membership function and trapezoidal function. It ranges from -40 to +40 for error and for de/dt it ranges from -20 to +20 for error input. The Fuzzy subset is Negative Big, Negative small, Zero, Positive small, Positive Big respectively termed as NB, NS, ZO, PS, PB. The membership function of input as error, de/dt and the output as Kp, Ki are shown in Figure 7, Figure 8, Figure 9 and Figure 10 respectively.

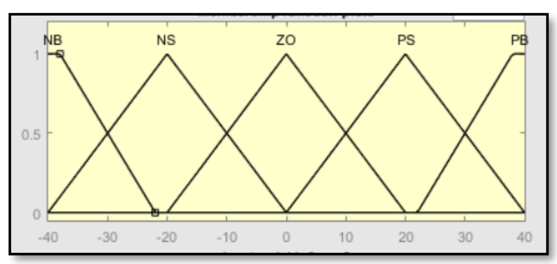

Figure 7. Membership function of Input error

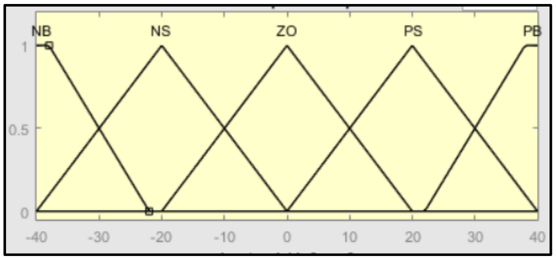

Figure 8. Membership function of input de/dt

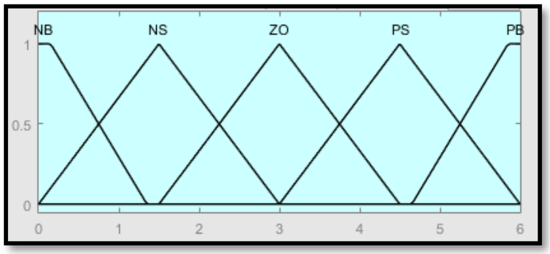

Figure 9. Membership function of output Kp

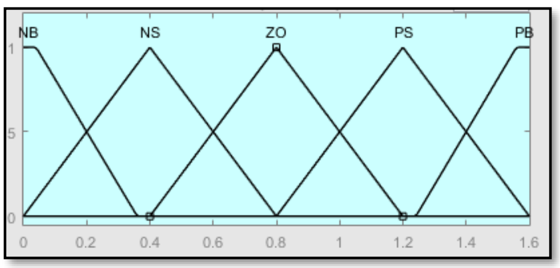

Figure 10. Membership function of output Ki

VII. RESULT & DISCUSSION

Figure 11 shows the response curve of the experimental open loop test 5% change in manipulated variable (MV).

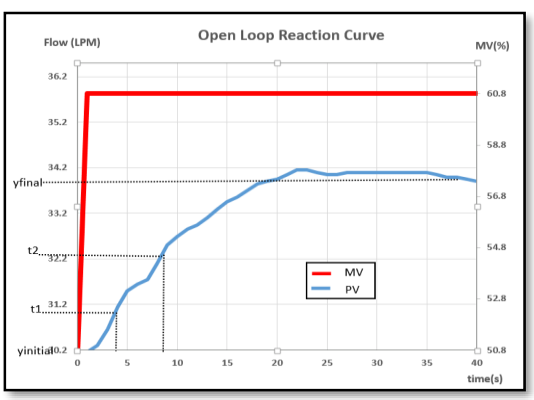

Figure 11. The open loop test process response

From the response curve, the calculated process gain is 0.39, the time constant is 6 seconds and dead time is 2 seconds. This process is considered as FOPDT (first order plus dead time) as it holds some delay at the beginning of the process response.

The PI controller's parameter adjustment is tabulated in Table III.

TABLE III. PI TUNING PARAMETER

	Proportional gain (Kp)	**Integral gain (Ki)**
1st tuning	6.9231	0.0586
2nd tuning	3.46155	0.1172
3rd tuning	1.73075	0.2344

The process response for Kp = 1.73037 and Ki = 0.2344 is as shown in Figure 12.

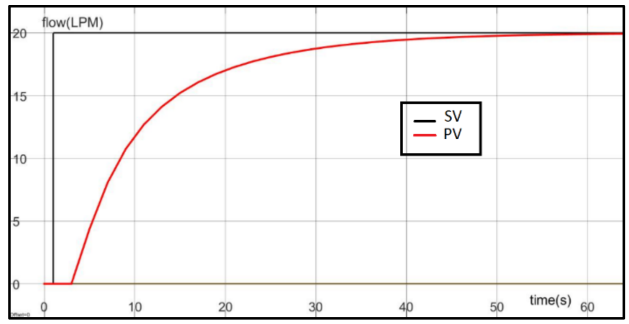

Figure 12. Process response for Kp =1.73075 and Ki = 0.2344

The settling time of the response is very slow but it has no overshoot. Since the system contains the integral action, the offset is eliminated completely [17]. However, the introduction of integral action alone does have a significant effect on response time. It can be seen that the response has good rise time, but very poor settling time.

Pertaining to this, another combination of PI controller parameters is selected that can minimize the proportional criterion to the process performance. The new combination of PI controller parameters is as shown in Table IV.

TABLE IV. PI FINE TUNING PARAMETER

	Proportional gain (Kp)	**Integral gain(Ki)**
Before tuning	1.73075	0.2344
1st tuning	1.73075	0.4644
2nd tuning	3.73075	0.2344
3rd tuning	2.73075	0.8344

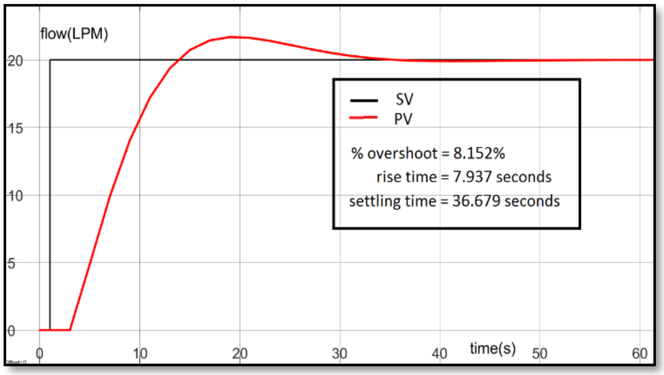

Figure 13. Process response for Kp =1.73075 and Ki = 0.4644

Figure 13 shows the best response curve with percent overshoot of 8.152%, a rise time of 7.937 seconds and a settling time of 36.679 seconds. This indicates that the response performs better after fine tuning in term of rise time and settling time to change of PI parameter.

However, in order to determine the two parameters in PI controller that minimize one of the integral criteria typically requires in the vicinity of 50 to 75 iterations [17].

Figure 14 shows the process response when self-tuning Fuzzy PI controller in implemented to the control loop. The performance of the process dynamic has improved with settling time of 17.80 seconds.

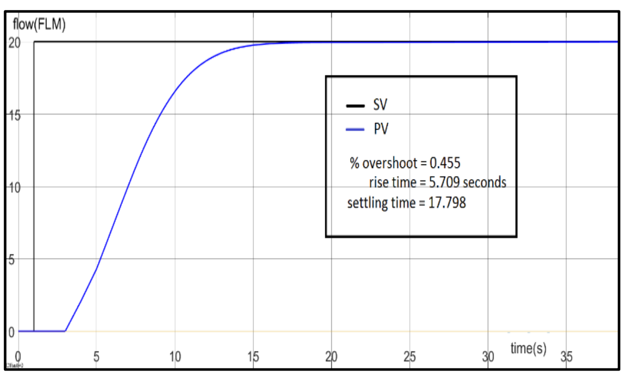

Figure 14. Process response using self-tuning Fuzzy PI controller

Figure 15 shows the comparison between PI controller and self-tuning Fuzzy PI controller process dynamic response.

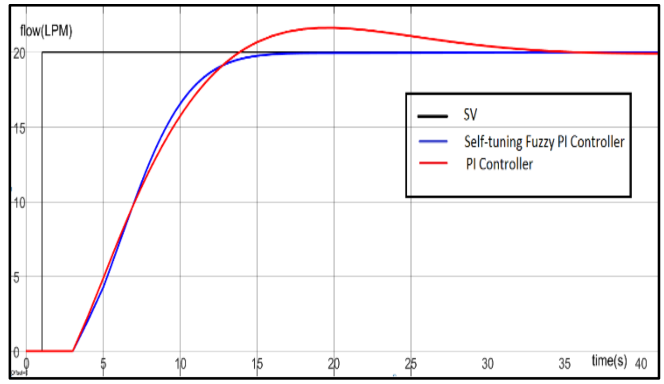

Figure 15. Response in comparison

Table V shows the difference in performance of water flow control for both controllers. It shows that conventional PI has larger percent overshoot, longer rise time and settling time. On the other hand, the process dynamic became fast when using self-tuning Fuzzy PI controller in the water flow control loop.

TABLE V. COMPARISON BETWEEN PI CONTROLLER AND SELF-TUNING FUZZY PI CONTROLLER PROCESS PERFORMANCE

Controller	% Overshoot	Rise Time(s)	Settling Time(s)
PI controller	8.152	7.937	36.679
Self-tuning fuzzy PI controller	0.455	5.709	17.798

VIII. CONCLUSION

Self-tuning Fuzzy PI controller uses the Fuzzy control rules to automatically tune the PI gains so that the controller will have better control performances than the conventional PI controller only.

Self-tuning Fuzzy PI controller has successfully enhanced the capability of conventional PI controller and provide faster response.

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