Fuzzy Logic and Control Strategies on a Sump

Nasser Mohamed Ramli, Nurul Izzati Zulkifli

Abstract—Sump can be defined as a reservoir which contains slurry; a mixture of solid and liquid or water, in it. Sump system is an unsteady process owing to the level response. Sump level shall be monitored carefully by using a good controller to avoid overflow. The current conventional controllers would not be able to solve problems with large time delay and nonlinearities, Fuzzy Logic controller is tested to prove its ability in solving the listed problems of slurry sump. Therefore, in order to justify the effectiveness and reliability of these controllers, simulation of the sump system was created by using MATLAB and the results were compared. According to the result obtained, instead of Proportional-Integral (PI) and Proportional-Integral and Derivative (PID), Fuzzy Logic controller showed the best result by offering quick response of 0.32 s for step input and 5 s for pulse generator, by producing small Integral Absolute Error (IAE) values that are 0.66 and 0.36 respectively.

Keywords—Fuzzy, sump, level, controller.

I. INTRODUCTION

SUMP has many functions such as to collect chemicals, hydraulic oil and other liquid disposal from oil and gas platform. However, at wastewater treatment system, sumps are used typically for collection and equalization of waste water flow from stream sewer lines or trenches before storage or treatment. Therefore, sump provides different functions for different systems [5].

Slurry filled sump is a multivariable system as it is highly interactive. The resulting control system has few variables such as sump volume, total flow rate in to the sump, out pumping rate from the sump and percentage of solids in as the inputs and few others including level percentage as the outputs. This system is also considered as an unstable process, due to the response of the sump level. In addition, it has been found out that, as a result of fractional time delay, sump system may give non-minimum response. A non-linear system like sump is also dynamic, owing to changing condition in the feed inlet other than long time delays. Therefore, it is essential to make sure that the level of the sump is under an effective and good control in order to prevent overflow. Hence, most industries are finding the best control strategy to be implemented to solve the problems and make resulting solutions more practical.

From literature review, PID and PI controllers are widely used in industry. It is commonly preferred controllers because the techniques are simple to use. They are widely used for tuning the process [12], [10]. There are several reasons for this. One of the main reasons is that these controllers are

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generally accepted as being too simple to execute compared to other sophisticated control strategies [1]. However, the limitation is due to large dead time in the process, and the performance of the system becomes unsatisfactory. Secondly, by using 'trial-and-error' method, this conventional controllers need to be tuned. The instrumentation of process plant is also conducted in a way it only suits the simple structure of the conventional controller. There are also few numbers of features that are not explicitly treated by these controllers such as time-varying parameters, time delays, multivariable interactions and non-minimum phase [12]. Not to mention, the math of the conventional controller may make the error sum to grow very large that the total controller signal stops from making sense. Hence, advanced control strategies, such as Fuzzy Logic controller, are able to deal with nonlinearities. This will allow the operators to merge uncertain information in an optimum way [3]. In fact, Fuzzy Logic control systems cover wider range of operating conditions, cheaper to develop, and they are more readily customizable in natural language terms. Overall, Fuzzy Logic controllers offer a promising alternative for industrial demand with many desirable features. Thus, the reliability of Fuzzy controller is proved through simulation studies by using MATLAB program and the results were compared with the conventional loop gain design method.

II. LITERATURE REVIEW

A. Feedback Control

Feedback control system has been widely used for more than 2000 years. The main objective of feedback control strategy is to produce an output that follows the desired set point with minimal error as possible. The set point however may be a fixed value or changing value which we called as servomechanism. Corrective action is taken regardless of the source of disturbances which may reduce the sensitivity of the controlled variable to disturbances and changes in process [10]. Unfortunately, feedback control only takes action after controlled variable mismatch the desired set point. Thus, there would be a period when the value of the output will be different than desired. This controller also tends to produce a very oscillatory response [7].

B. Feedforward Control

The feedforward control is widely used in the mid-1970s and late 1980s [4]. Feedforward control method can avoid the tardiness of feedback control. A feedforward controller enhances control performance by measuring the disturbance directly using a sensor before it affects the process [9]. Feedforward element uses the obtained disturbance signal to compute and program preventive control actions that will

counter the effect of the disturbance just as it influences the measured variable. Feedforward control can give an accurate result if the mathematical model and parameters are of sufficient knowledge.

Although a feedforward element can dramatically reduce the impact of a disturbance, it can never offer absolute disturbance rejection. The difficulty with feed-forward control is due to the effects of the disturbances on the process. The disturbances are measured because they could affect the process. No sensor or anticipation can provide complete information about future effects of an infinity variety of possible perturbations and therefore feedforward is bound to make mistakes. With a good control system, a small error will be produced, nevertheless the problem is that they will accumulate and destroy the system in the long run. Thus, to achieve the best result, combinations of feedback and feedforward are commonly used. The combination of these control methods give both benefits of feedback control which controls unknown disturbances and the benefits of feedforward control that responds to disturbances before they can affect the system [6].

C. Cascade Control

Cascade control is one of the advanced applications that allow the controller to limit the negative impact by reacting faster to disturbances. This control strategy is used with the aim to achieve fast disturbances rejection before it reaches the other parts of the process.

Cascade control is more difficult to implement because architecture comprised of two ordinary feedback controllers. The basic cascade control system consists of two control loops known as secondary loop and primary loop.

The cascade control method allows the process to reach its set point quickly while minimizing overshoot since any disturbances coming in will impact the secondary loop before they affect the primary loop. A cascade control system offers better performance compared to a traditional single-measurement controller. The main benefit of cascade control system is that it has 2 controllers which are primary and secondary as it could address multiple disturbances. However, cascade control also has drawbacks. Obviously, by having more controllers and sensors in the process will have high equipment cost. Besides, cascade control systems are also more complex than conventional controllers since it requires twice as much tuning. Therefore, using a cascade is a better option only if conventional methods failed.

D. Fuzzy Logic

Fuzzy logic and neural network control have become more advanced compared to conventional PID controller and they are widely used in current research. Fuzzy logic control system was proposed by Zadeh, a Professor at University of California [2]. Current technologies that used fuzzy as control system are flight control system, camcorder stabilization, and anti-lock braking system [9], [11].

Fuzzy logic is a form of many-valued logic or probabilistic logic. Variables in most control system take either true or false values, but fuzzy logic variables have a truth value that ranges in degree between 0 and 1. Therefore, the true value may be in between completely true and completely false. Thus, Fuzzy logic has been drawn-out to promote the concept of partial truth. Fuzzy logic is a part of artificial intelligence that mimics human's action by reasoning the degree of truth or false which computer cannot interpret it. This control system makes it easier to mechanize tasks that are successfully performed by humans [8].

There are few benefits of fuzzy logic controller. Fuzzy logic controller is well-suited with cheap sensors, 4-bit or 8-bit one-chip microcontroller chips and low-resolution analog-to-digital converters. Besides, this system can be easily upgraded by adding new rules or new features to enhance the performance. This simple-to-design and implement control system is very robust and can be easily modified. Moreover, non-linear functions of arbitrary complexity can be modelled to a desired degree of accuracy by using Fuzzy Logic. It also gives better performance than the conventional controllers. Fuzzy controllers could have multiple inputs and outputs which are simple to use, quick and cheaper to implement. Despite that, Fuzzy logic has its drawbacks. Firstly, it has many unclear options. Due to many choices of defuzzification, conjunction, disjunction and implication, thousands of different fuzzy system configurations may arise. On top of that, the performance-robustness tradeoff is not usually taken into account in Fuzzy Logic control as the robustness is often assumed as fundamental property. Hence, Fuzzy Logic will be easily practiced for non-linear plant model.

III. METHODOLOGY

A. Developing Dynamic Model of Sump

To develop dynamic equation, few assumptions have to be made:
1. The slurry is well-mixed in the sump.
2. The agitator suspends the slurry in the sump.
3. There is no change in particle size.

The dynamic behavior of the sump is as:

$$\frac{dm_{solid}}{dt} = m_{solid\ in} - m_{solid\ out} \tag{1}$$

$$\frac{dm_{water}}{dt} = m_{water\ in} - m_{water\ out} \tag{2}$$

$$\frac{m_{solid}}{m_{water}} = \frac{m_{solid,out}}{m_{water,out}} \tag{3}$$

$m_{solid,in}$ is solid mass flow rate in, $m_{solid,out}$ is solid mass flow rate out, $m_{water,\ in}$ is water mass flow rate in and $m_{water,out}$ is water mass flow rate out.

$$slurry\ volume\ in\ sump = \frac{m_{solid}}{\rho_{solid}} + \frac{m_{water}}{\rho_{water}} \tag{4}$$

$$level = \frac{slurry\ vol}{sump\ vol} \tag{5}$$
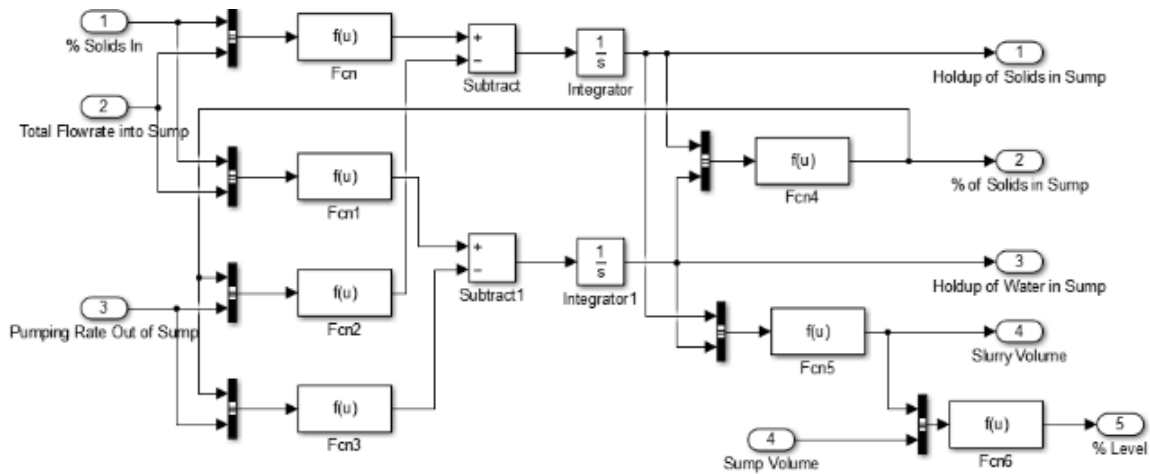
Fig. 1 Subsystem of Sump Tank

TABLE I
OPERATING CONDITIONS

Step Input		Pulse Generator	
Solid	40	Solid	40
Flow In	100	Flow In	100
Sump Volume	50	Sump Volume	50
Flow of Solid In	40	Flow of Solid In	40
Flow of Water In	60	Flow of Water In	60
Step Size	5	Amplitude	1
Step Time	5	Period	10
Solid Density	2.65	Solid Density	2.65
Water Density	1	Water Density	1
Load Time	5	Load Time	5
Load Size	0	Load Size	5

The dynamic modeling for the sump is focusing on two components in the sump which are the solid and the water. Algebraic solution, integration, and simulation in MATLAB were used to solve the dynamic modelling of the sump.

The first thing to determine after developing dynamic model are mass of water, mass of solid in the sump, slurry volume and level in the sump. By using simultaneous equation method, the equation was solved. Thus, at t = 0, mass of solid determined is 40 tonnes and mass of water is 30 tonnes. Taking specific gravity for solid is 2.65 and 1.0 for water into calculation to determine the sump volume, which is 50 m^3.

The simulation model in MATLAB Simulink was built based on these predefined parameters and operating condition.

After developing dynamic equation of the sump, the equation was then modeled in the MATLAB Simulink as a subsystem.

In this paper, there are 4 types of control strategies which are feedback, feedforward, cascade and fuzzy logic controller.

In order to design, the fuzzy logic controller is based on rules. Besides, it did not have analytic formula to use for control specification and stability analysis. The fuzzy controller is favorable than the conventional PID control system, because the error is less and perform better as the settling time is faster and no overshoot [13].
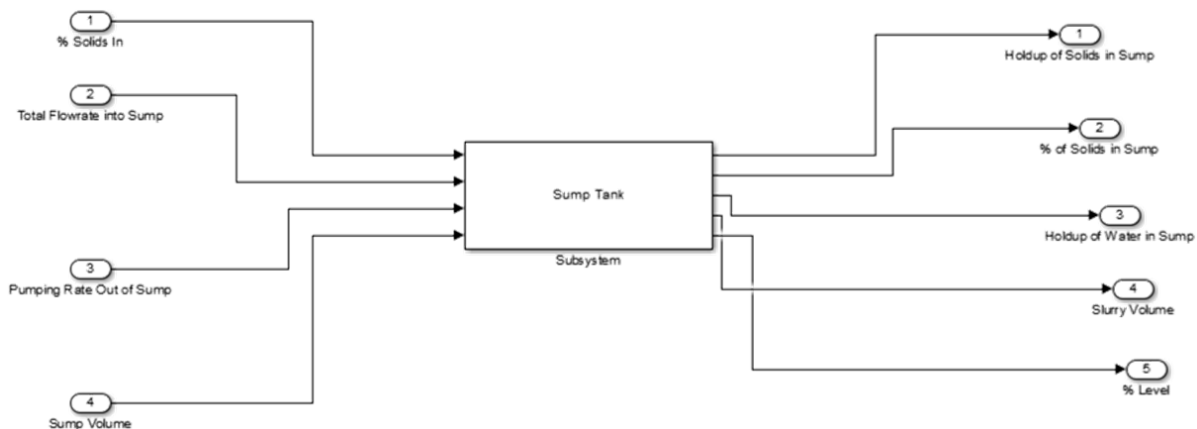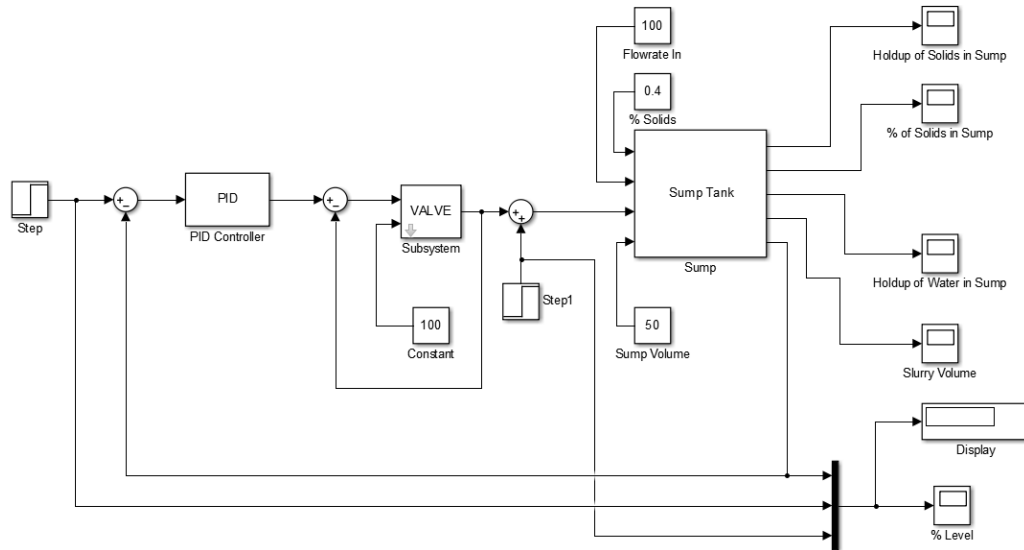

Fig. 2 Design of Sump Tank

Fig. 3 Step Input SIMULINK Design for PID Controller
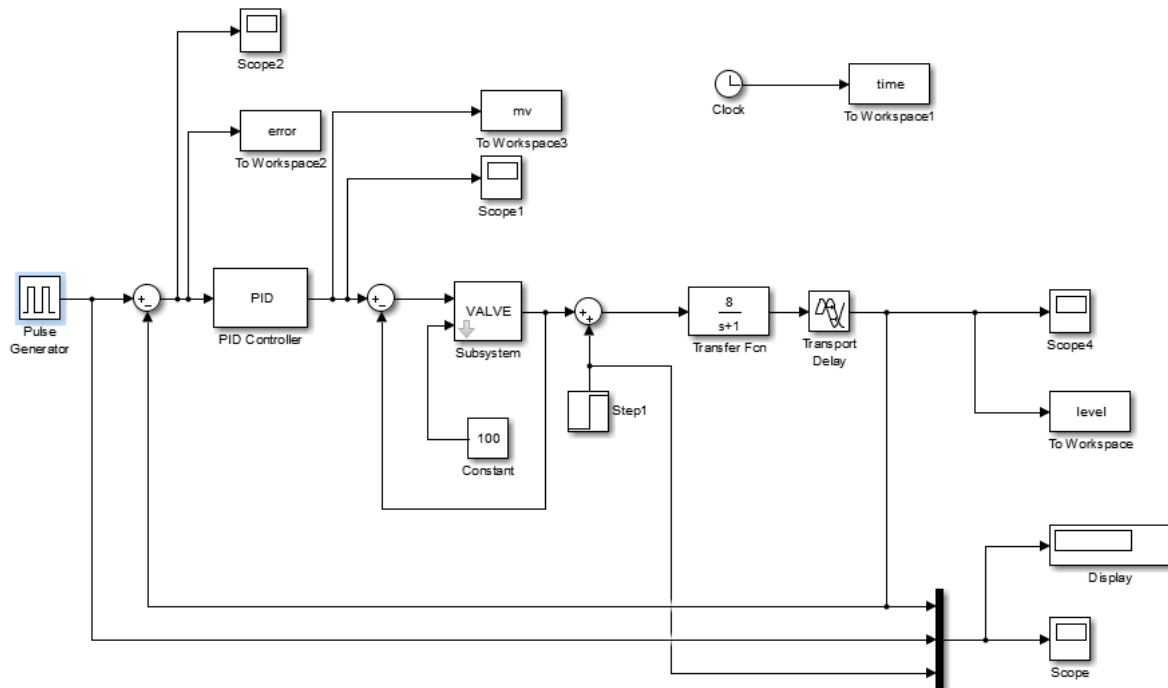

Fig. 4 Pulse Generator SIMULINK Design for PI Controller

The fuzzy set rules (base) are described as:

1. If "Error is very Negative High" Then "Controller Output is very Positive High"
2. If "Error is very Negative Low" Then "Controller Output is very Positive Low"
3. If "Error is very ZERO" Then "Controller Output is very ZERO"
4. If "Error is very Positive Low" Then "Controller Output is very Negative Low"
5. If "Error is very Positive High" Then "Controller Output is very Negative High"
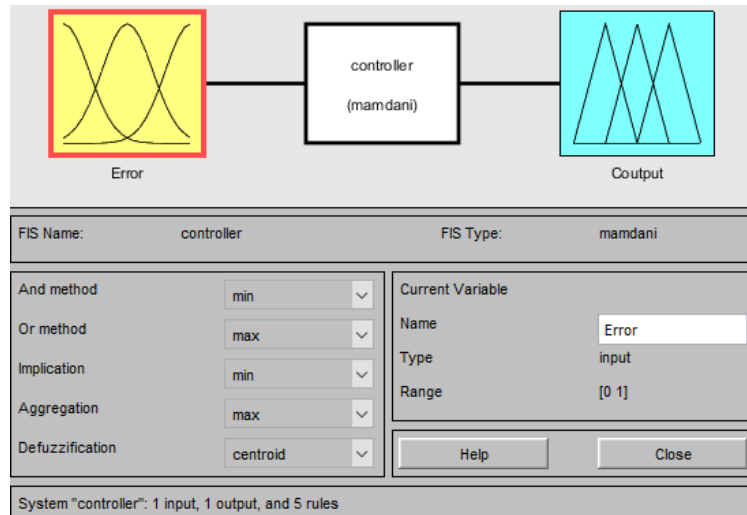
Fig. 5 The Concept of Mamdani based Fuzzy Inference System
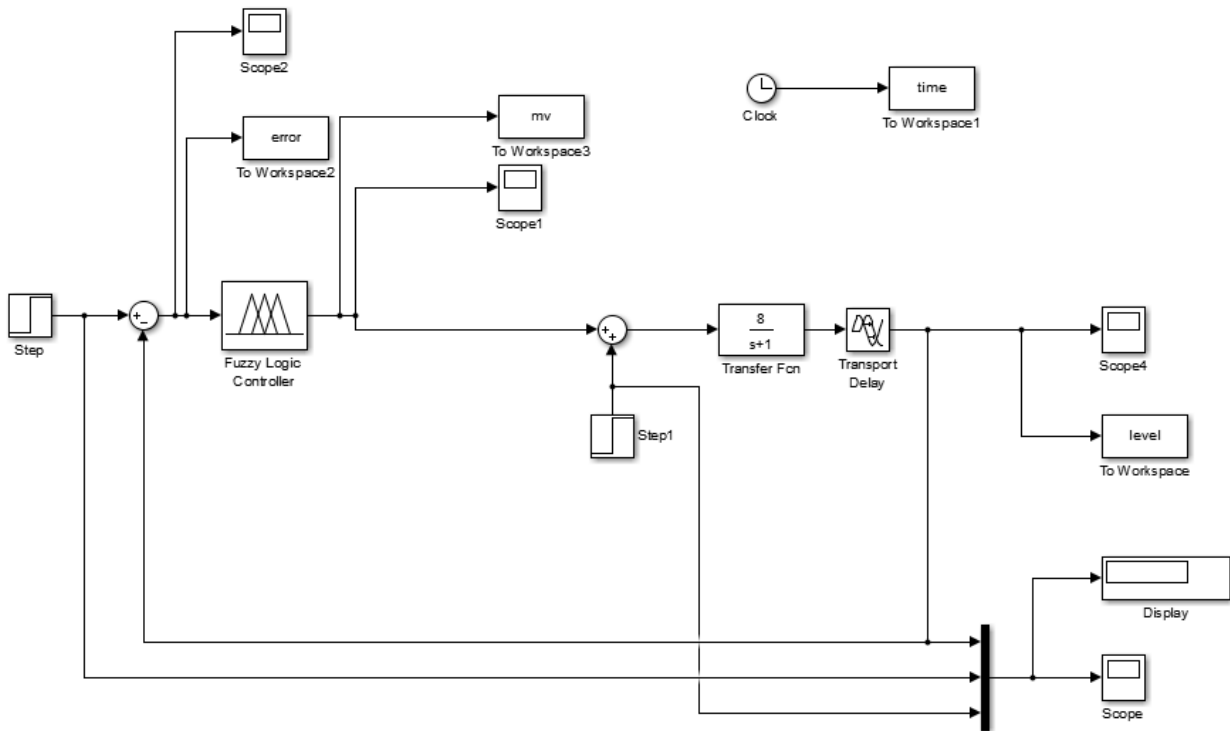

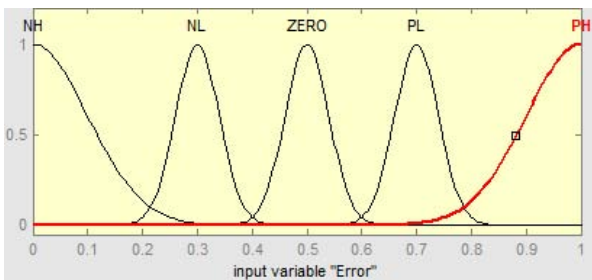Fig. 6 Proposed Simulink Design of Fuzzy logic

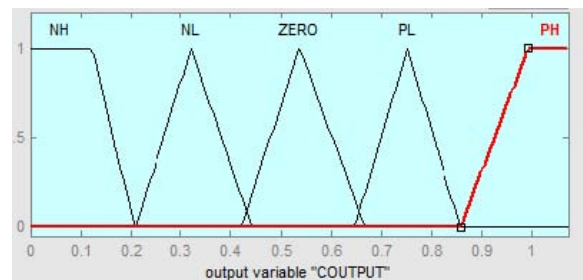
Fig. 7 Inputs Membership Function

Fig. 8 Outputs Membership Function

Tunings used in this study are Cohen Coon, Integral of Absolute Error (IAE) and Ziegler-Nickels. As shown in the results, the optimum tuning was found to be Cohen Coon with the formula given below:

$$\text{Servo tuning} = K_c = \frac{0.758}{K_m}\left(\frac{T_m}{t_m}\right)^{0.861} ; T_i = \frac{T_m}{1.020 - 0.323\frac{t_m}{T_m}} ;$$

$$T_d = 0.1 < \frac{t_m}{T_m} < 1.0$$

$$\text{Regulator tuning} = K_c = \frac{0.984}{K_m}\left(\frac{T_m}{t_m}\right)^{0.986} ; T_m = \frac{T_m}{0.608}\left(\frac{t_m}{T_m}\right)^{0.707} ;$$

$$T_d = 0.1 < \frac{t_m}{T_m} < 1.0$$

IV. RESULTS AND DISCUSSION

For both step and pulse generator input, different behaviors can be observed from Figs. 9 and 10 when a set point change was introduced. PID controller produced an 'overshoot' before settled down to a new set point. However, the level response was unstable as it kept on fluctuating. As for PI and Fuzzy controllers, both showed less fluctuation and produced no 'overshoot'. But, in terms of time taken to reach the new set point, Fuzzy Logic controller reacted faster than PI controller. For step input, it took only 0.32 seconds to reach the set point for fuzzy controller, PI and PID controller took about 15 seconds. For pulse generator, fuzzy controller took about 5 s to reach new set point while PI controller took about 7.1 s to reach highest value at 0.9% before decreasing for a new set point.
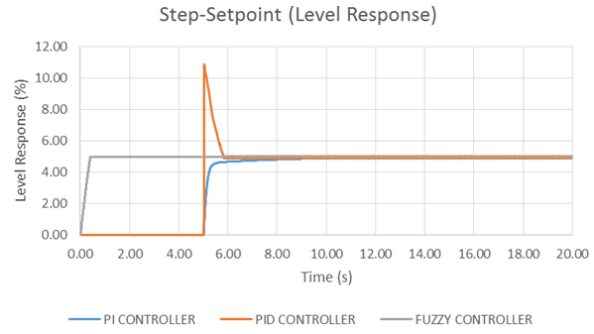

Fig. 9 Level Response for Step (Set Point Change)

In consideration of step input, Fuzzy Logic Controller managed to eliminate error after fluctuating for 13s while PI Controller took about 19.8 s to reach steady state. Even though it took longer time than PID controller to reach 0% of error response, the error did not fluctuate anymore after T=13. On the other hand, for PI controller, the error fluctuation decreases after it increased and decreases again when pulse generator was used as an input. Meanwhile, PID controller produced an inconsistent error response with vigorous oscillation. Fuzzy controller showed a different fluctuation as the error response was decreasing from 1% to 0% from t=0 to t=5. However, at t=7, Fuzzy controller showed negative response up to -1% before it increased again until t=10s.
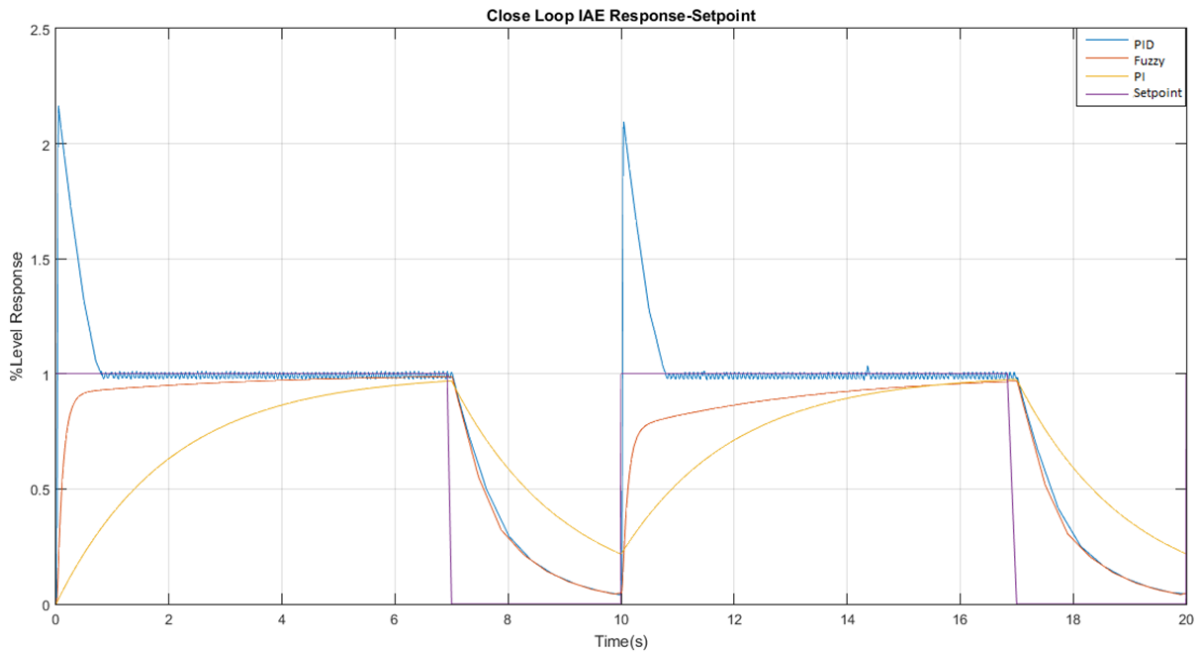

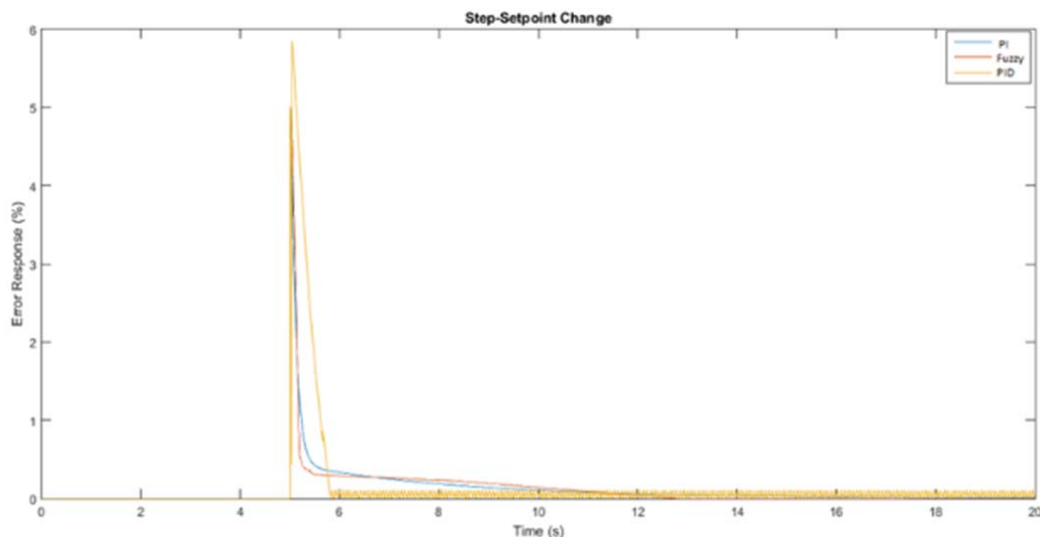Fig. 10 Level Response for Pulse Generator (Set Point Change)

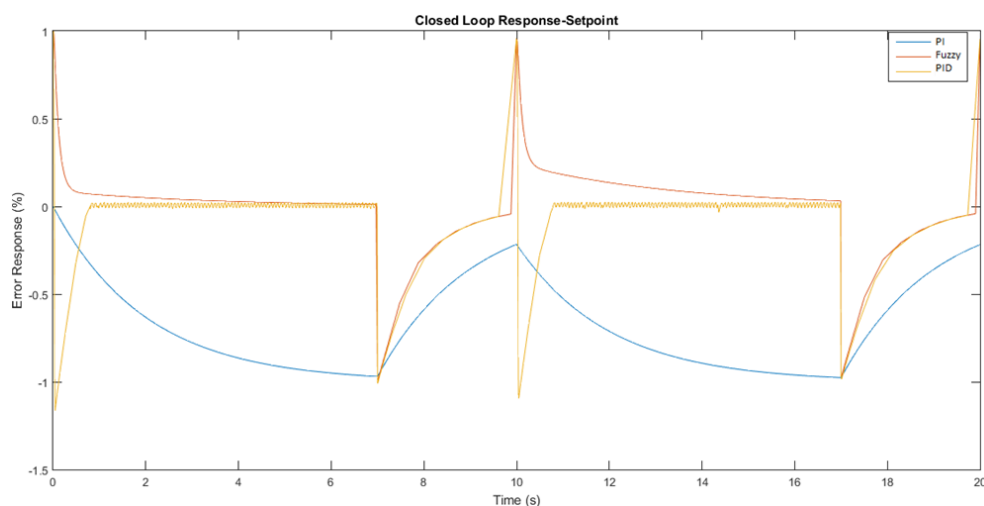Fig. 11 Error Response for Step (Set Point Change)

Fig. 12 Error Response for Pulse Generator (Set Point Change)

In order to determine the best controller performance, the index of Integral of the Absolute Error (IAE) value was taken into consideration. The IAE at minimum value was favorable in order to determine best controller performance.

Looking at Table II, Fuzzy Controller with a feedforward system gave the best controller performance by having the lowest value of IAE (0.66) for a step input. It was followed by the PI Controller with value of 2.06 and 1.39 for PID Controller. On the other hand, the IAE values were different for pulse generator input. Even though it was leading by Fuzzy Logic controller, Fuzzy Logic obtained the lowest value of 0.36 and followed by Fuzzy (0.64) as well as PID controller (1.39). These controllers seem to be performing at optimum to maintain the level in order the IAE values to be small. Nonetheless, all of the controllers managed to maintain the flow at the acceptable region. Overall, fuzzy controller gave the best overall performance as it responses quickly to the new change and had less fluctuation as well as minimum IAE

value. A stable response for set point changes and disturbance changes indicate that the controller is good. Therefore, it can be concluded that the best controller to cater sump level is fuzzy logic controller.

TABLE II
IAE VALUES FOR STEP INPUT

Controller Type	PI	PID	Fuzzy
Controller Strategy	Feed back	Feed back	Feed forward
IAE Value	2.06	1.39	0.66

TABLE III
IAE VALUES FOR PULSE GENERATOR

Controller Type	PI	PID	Fuzzy
Controller Strategy	Feed back	Feed back	Cascade
IAE Value	0.64	2.00	0.36

V. Conclusion

Three different controllers are conducted by using four control strategies (Feedback, Feedforward and Cascade) for the slurry-filled sump level via MATLAB. Simulated results show that Fuzzy Logic controller results in quick response without overshoot and small integral absolute error. Besides, this controller also shows less fluctuation for both step input and pulse generator. Moreover, this method has good ability to adapt to the tuning parameters for changes in process dynamics. To summarize, the fuzzy logic controller has been proved to be an efficient method in the sump level process control. This method can be also used in a variety of nonlinear process control systems with large transportation lag processes. Therefore, slurry sump level will be in control and no overflow shall occur.

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