BOILER DRUM LEVEL SINGLE LOOP FUZZY LOGIC CONTROL AT MODEL BDT921

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***Abstract*—** This study had been conducted to determine the best input and output parameter Fuzzy Logic Controller and to study the performance of level process using Fuzzy Logic System. For the analysis of performance of Fuzzy Logic, the boiler drum level controller at model BDT921 PCTS data will be used by using Emerson programming. This is done by tuning the Fuzzy Logic Control (FLC) variables which are analyzed the error, change of error and change of output. The collection of data on the variables that will contribute to yield the best performance output is obtained. All these data are then inserted in Emerson programming to be determined the settling time, decay ratio, number of oscillation and integral analysis error (IAE) analysis for each variable could be performed. In conclusion, based on the tuning FLC parameters such as fast response and settling time, small decay ratio, no overshoot, short distance peak to set point, small integral absolute error (IAE) analysis are the criteria that would be final decision for the best performance of Fuzzy Logic Control system.

Keywords*— *boiler drum, better performance, decay ratio, Fuzzy Logic, level control

I. INTRODUCTION

A boiler system is one of the main equipment involved in thermal power plant and controlling the water level is a critical operational in the boiler system. In the circulating fluidized bed (CFB) boiler, the balance of boiler load and water supply are depending on the water level. When the water level is too low then it will leading to boiler drum explosion. However, if the water level is too high, it will affect the separator of steam water and cause damage to the turbine. Therefore, drum water level should be controlled and take serious action to ensure is the water level is not exceed the limit to prevent serious injuries. [2,3]. In fact, the explosion of boiler drum occurs in a plywood factory at Talkatora Industrial Area, Luck and also India, on 23 February, 2011 are related to the superheating of the boiler drum, as the water level became critically low and malfunction of level control system in plant.[1]

Furthermore, boiler drum level have their limitations on specific condition and properties that must be controlled. Plus, the design of boiler drum are specified and manufactured by the boiler manufacturer. If the level in the boiler drum exceeds the limits, it may generate alarm and force the level control loop into manual mode. Failure of generating alarm to control the level of drum will cause water carryover into the super heater or the turbine damage and may lead to boiler explosion. It will increase the maintenance costs of the turbine or boiler if damage. Besides that, when the water wall tubes is operated in overheated temperature and pressure, it may cause tube ruptures and serious accidents. This will be resulting in operation cost due to the expensive repairs, downtime, and injury or death to personnel. Therefore, by using Fuzzy Logic Control system method, the cost spent on the maintenance and operation cost can be reduced and also the number of manpower or operator can be eliminated in which FLC can formulated human decision making with an ability to generate precise solutions from uncertain or approximate information.

The application of fuzzy logic is applied for solving problems of controlling water level in boiler drum and combustion quality control is presented. Fuzzy control rules is obtained from operator knowledge based on the relative relevance ruling criteria for existing boiler room. Fuzzy control model was adjusted for given problem with simplification of output variables in order to speed up final calculation. Fuzzy logic based control can be good choice if the controller designer has a sufficient amount of operational knowledge. [6]

Fuzzy Logic control could exhibit a lot of advantages, such as fast response, small rise time, small settling time, small overshoot, strong set point tracking and robustness. The fuzzy logic controller (FLC) is advantageous to use as it does not require a precise mathematical model and the most effective methods for precise control system. [5]

The study is focusing on determination of the best input and output of boiler drum level control and to obtain the best performance of Fuzzy Logic control parameter to be used in the system. There are several controllability analysis in this research to be analyzed. The performance of a boiler system process response depends on the intended settling criteria such as settling time (Ts), number of oscillation, decay ratio, distance peak to set point and the quality of integral absolute error (IAE).

II. METHODOLOGY

There are three variables or parameters being examined in this research by using Emerson programming. Fuzzy Logic Control parameters value such as error, change of error and change of output. All data needed of these variables are collected and analyzed by evaluating settling time (ts), decay ratio, integral absolute error (IAE), distance first peak to set point and number of oscillation analysis to investigate which variables will give contribution to the performance of system in the presence of load disturbance test is applied at early stage and tuned at set point 300mm, 500mm and 700mm.

A. Identifying Possible Variable

There are five data involved in this research which are settling time, decay ratio, number of oscillation and integral analysis error (IAE) analysis.

B. Collection of Data

All the data are collected from Emerson programming at the different of tuning FLC parameter.

C. Fuzzy Logic Design

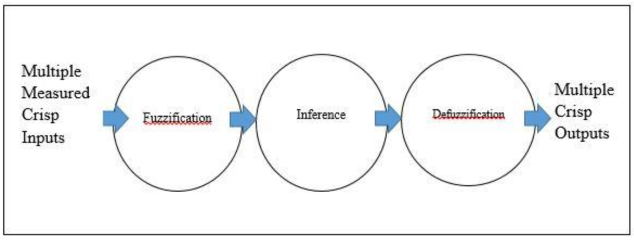

Figure 1: Fuzzy Login Design

(i) Fuzzification

Fuzzification is defined as the process actual measured input values are mapped into fuzzy membership functions.

(ii) Inference

Once membership functions have been defined for input and output variables, a control rule base can be developed to relate the output actions of the controller to the observed inputs. This phase is known as the inference, or rule definition portion, of fuzzy logic.

Table 1: Fuzzy Logic Rule:

Number	Rule
Rule 1	If error is N and change in error is N, make change in output POSITIVE
Rule 2	If error is N and change in error is P, make change in output ZERO
Rule 3	If error is P and change in error is N, make change in output ZERO
Rule 4	If error is P and change in error is P, make change in output NEGATIVE

(iii) Defuzzification

After the fuzzy logic controller evaluates inputs and applies them to the rule base, it must generate a usable output to the system it is controlling. The fuzzy logic controller must convert its internal fuzzy output variables into crisp values that can actually be used by the controlled system.

There are two common methods can be performed which are:

a) Maximum defuzzification method
b) Centroid calculation defuzzification method.

D. Experimental procedure

1. Model BDT921 graphic was chosen to display and the level LIC11 controller shall be selected to **Fuzzy Logic Control (FLC).**

2. 3 Element Selector Switch is switched to "1-Element" position, and make sure the LIC11 Controller is at Auto mode. Heat Exchanger Temperature control selector is changed to "FIC12" position.

3. Load Disturbance Test is applied by switching the FIC12 controller to Manual Mode and set its Manipulated Output (OUT)=45%

4. FLC Tuning parameters (Error, Change of Error and Change of Output) and Set point (SP) were set up by using the First trial FLC Tuning parameter values in table below and remains in the AUTO (AUT) mode throughout the experiment and make sure that the valve positioned at LCV11 is connected.

Boiler Drum Level controller
Controller : LIC11
Set point : 50mm

First (1) Trial FLC Tuning Parameters
- **Error (e)** : 8.000%
- **Change of Error (Δe)** : 0.180%
- **Change of Output (Δu)** : 1.850%

5. Filled up the water level by start the Boiler Drum Inflow pump P12 first, then start the Outflow pump P11 when the tank T11 level rises above 300mm.

6. LIC11 Process Historical Trend was selected to observe the level response.

7. Inflow Load Disturbance is applied to boiler Drum Inflow when the level response is within ±5mm of its Set point (SP). Perform the Inflow Load Disturbance as follows:
   i. LIC11 Fuzzy Logic Controller (FLC) is switched to Manual mode and decrease its manipulated Output by 10%.
   ii. LIC11 Fuzzy Logic Controller (FLC) is changed to BACK Auto mode.

8. LIC11 Process Historical Trend is selected to observe the performance of Boiler Drum level response similarly

9. Repeat the above procedures 4 and 7 for next FLC trial. Tuning parameter values in table below.

Table 2: FLC tuning parameter

Trial PID	Set point (mm)	Error (e)	Change of Error (Δe)	Change of Output (Δu)
I	500	8.000	0.180	1.850
II		5.000	0.180	1.850
III		5.000	0.180	15.000
IV		User's defined FLC tuning parameter setting		

III. RESULT AND DISCUSSION

There are three variables or parameters being examined in this research by using Emerson programming. Fuzzy Logic Control parameters such as error, change of error and change of output. All data needed of these variables are collected and analyzed by evaluating settling time, decay ratio, integral absolute error (IAE), distance first peak to set point and number of oscillation analysis to investigate which variables will give contribution to the performance of system in the presence of load disturbance test is applied at early stage and tuned at set point 300mm, 500mm and 700mm.

A. Effect of Fuzzy Logic Control Tuning Parameter at Set point 300mm

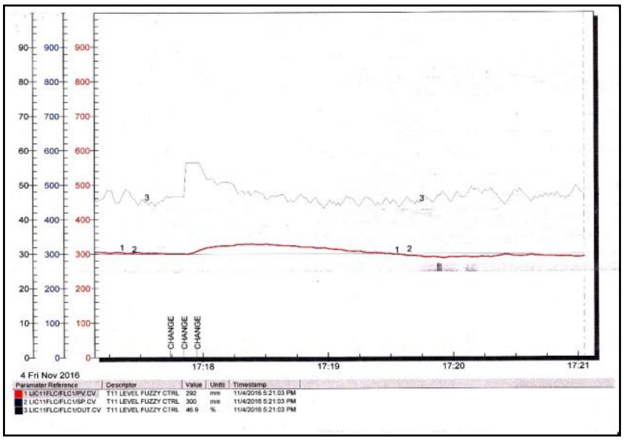

Figure 2: Fuzzy Logic Control Tuning Parameter I at 300mm

Parameter I
Error, e : 8.000 %
Change of Error, Δe : 0.180 %
Change of Output, Δu : 1.850 %

Table 3: Performance of Parameter I at Set point 300mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscilla tion
I	1.57	-	1.58	0.05	1

Figure 2 shows that response of Fuzzy Logic Control tuning system were set up at set point, error, change of error and output at 300 mm, 8.00%, 0.180% and 1.85% respectively. It can be seen from the graph, by performing the load disturbance test will make the process variable become underdamped type. There is change in set point and controller action become slower response towards the set point and stable process.

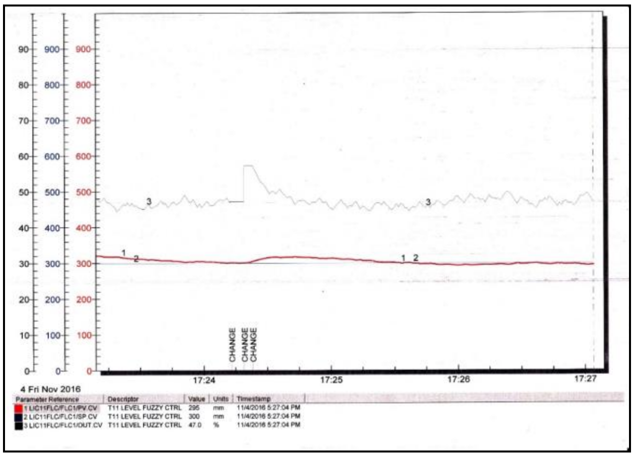

Figure 3: Fuzzy Logic Control Tuning Parameter II at 300mm

Parameter II
Error, e : 5.000 %
Change of Error, Δe : 0.180 %
Change of Output, Δu : 1.850 %

Table 4: Performance of Parameter II at Set point 300mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No of oscilla tion
II	1.17	-	0.51	0.003	1

Figure 3 comparing the changes of process response become faster in settling time by decreasing the value of error and remain the changes of error and output values in second trial PID. There is no decay ratio which is no oscillation is reduced during one complete cycle to reach set point and steady state. Meanwhile, the distance first peak to set point become smaller compared to first tuning parameter. Hence, integral absolute error is calculated to measure the performance of tuning parameter is being reduced.

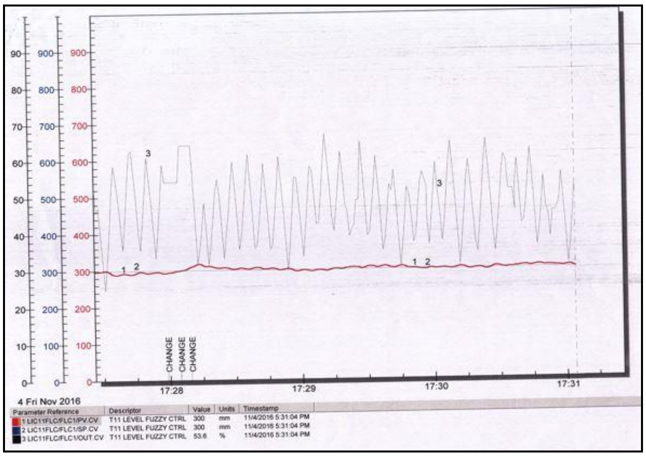

Figure 4: Fuzzy Logic Control Tuning Parameter I at 300mm

Parameter III
Error, e : 5.000 %
Change of Error, Δe : 0.180 %
Change of Output, Δu : 15.000 %

Table 5: Performance of Parameter III at Set point 300mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No of oscillation
III	0.42	0.67	2.1	0.003	24

In Figure 4 illustrates that the graph is fluctuated and oscillatory due to the increasing value of change of output up to 15 percent. This condition resulted in increasing the integral absolute error within the process to achieve the steady state. Furthermore, the oscillatory response was affected by the increasing number of oscillation towards the set point. Hence, decay ratio was calculated after reduction of oscillation after complete one cycle. The settling time become smaller and make the controller action turning into faster process response. By comparing all of these three graph, parameter II is the best tuning performance for the set point 300mm.

B. Effect of Fuzzy Logic Control Tuning Parameter at Set point 500mm

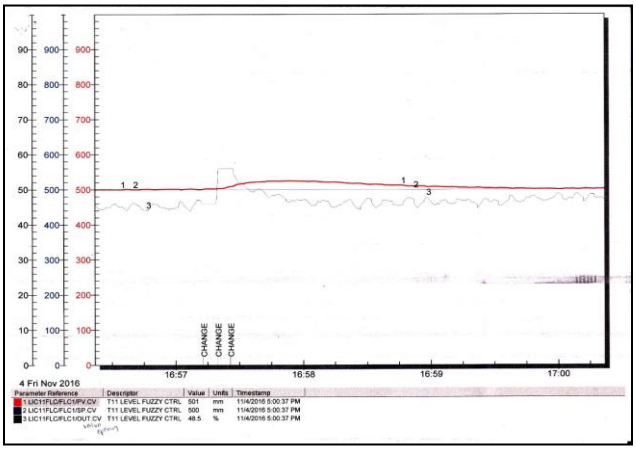

Figure 5: Fuzzy Logic Control Tuning Parameter I at 500mm

Parameter I
Error, e : 8.000 %
Change of Error, Δe : 0.180 %
Change of Output, Δu : 1.850 %

Table 6: Performance of Parameter I at Set point 500mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscillation
I	2.33	-	1.20	0.003	1

Figure 5 represent that the performance of tuning parameter was set up at set point at 500mm. For parameter I, error, change of error and output was tuned at 8.00%, 0.180% and 1.85% respectively. Based on the graph, the controller able to handle the load disturbance test in the response process. Besides that, IAE integrates error over the time was estimated and the process variable become underdamped type response. Thus, by tuning process the settling time turn to slower response to get the stable process and reached set point.

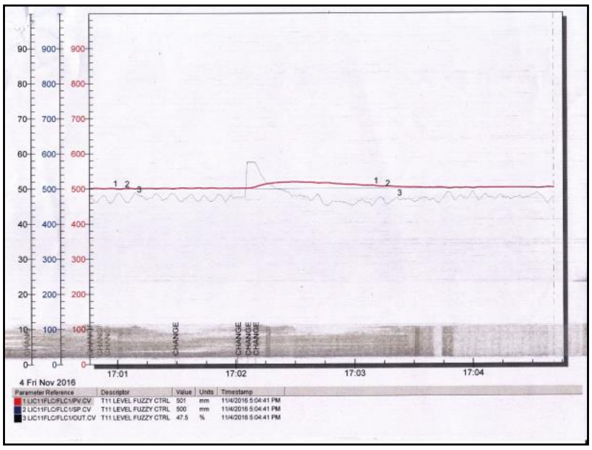

Figure 6: Fuzzy Logic Control Tuning Parameter II at 500mm

Parameter II
Error, e : 5.000 %
Change of Error, Δe : 0.180 %
Change of Output, Δu : 1.850 %

Table 7: Performance of Parameter II at Set point 500mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscillation
II	1.52	-	0.09	0.003	1

Figure 6 displays that the process variable changes in the graph when the value of error was integrated by IAE analysis. By reducing the error, the IAE was reduced and become stable without decay ratio or oscillation after complete one cycle. Then, the response becomes faster when the settling times to achieve set point become smaller.

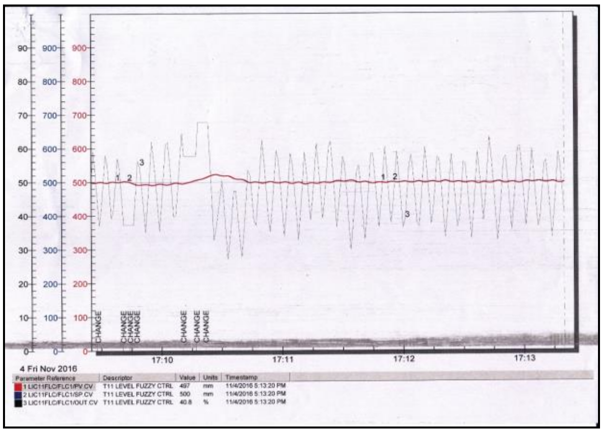

Figure 7: Fuzzy Logic Control Tuning Parameter III at 500mm

Parameter III
Error, e : 5.000 %
Change of Error, Δe : 0.180 %
Change of Output, Δu : 15.000 %

Table 8: Performance of Parameter III at Set point 500mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscillation
III	0.25	0.75	0.37	0.004	26

In Figure 7, it shows that the changes of output contribute to the frequency of opening valve in the boiler drum level control system. By increasing the value of output, the graph is vigorously fluctuated and makes faster response towards set point. The time taken to nearly set point which is settling time is much smaller and faster. The integration of error estimated by IAE analysis increase as decay ratio also increases. In this situation, opening valve is working hard that will cause costly operation process due to the high maintenance of opening valve. Hence, this is not suitable condition to operate in order to achieve the best performance. The best performance among three graph at set point 500mm is tuned process by using parameter II.

C. Effect of Fuzzy Logic Control Tuning Parameter at Set point 700mm

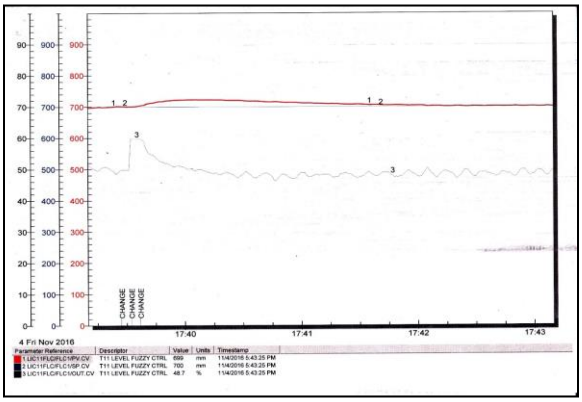

Figure 8: Fuzzy Logic Control Tuning Parameter I at 700mm

Parameter I
Error, e : 8.000
Change of Error, Δe : 0.180
Change of Output, Δu : 1.850

Table 9: Performance of Parameter I at Set point 700mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscillation
I	2.55	-	1.59	0.004	1

Based on the graph in Figure 8, it can be described the response changes slow motion after tested a load disturbance test at the beginning process. The stable process make the settling time become slower to reach the set point at 700mm by tuning the FLC parameter I. Thus, the integration of error was evaluated at the highest value of error due to the longer process response in this parameter I.

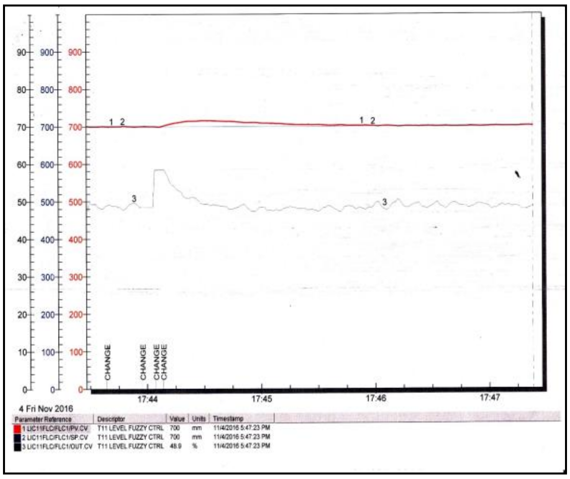

Figure 9: Fuzzy Logic Control Tuning Parameter II at 700mm

Parameter II
Error, e : 5.000
Change of Error, Δe : 0.180
Change of Output, Δu : 1.850

Table 10: Performance of Parameter II at Set point 700mm

Trial PID	ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscillation
II	1.72	-	0.37	0.003	1

Referring to the Figure 9 above, the value of Integral Absolute Error (IAE) much smaller after disturbance test is handled. By comparing the process variable Parameter I, this graph shows better performance in which faster response take place when the settling time taken to arrive the steady state is more short.

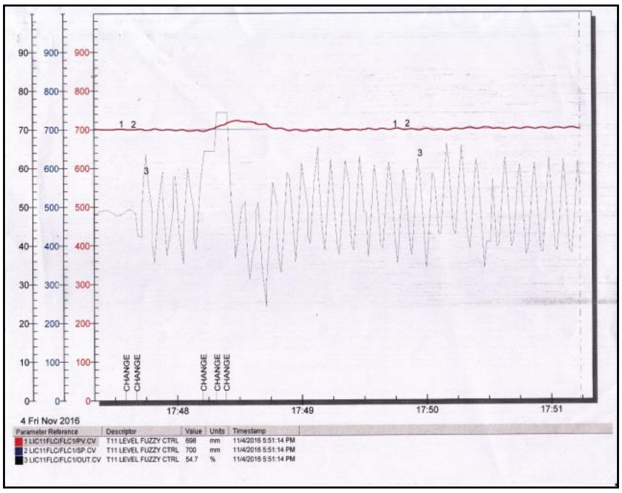

Figure 10: Fuzzy Logic Control Tuning Parameter III at 700mm

Parameter III
Error, e : 5.000
Change of Error, Δe : 0.180
Change of Output, Δu : 15.000

Table 11: Performance of Parameter III at Set point 700mm

Trial PID	ts(s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscillation
III	0.48	0.88	4.93	0.004	23

In Figure 10, the experimental graph represent that the correlation between the change of output and the process variable response. Increasing the change of output and set point at 700mm will affect the undesirable performance in which the integration of error becomes higher. The opening valve is more frequently open and close the level controller in the boiler drum and make some noise. This condition will cause high cost maintenance.

Table 12: Summary performance of FLC parameter

	Set point (mm)	Ts (s)	Decay Ratio	IAE (m^2)	Distance first peak to set point (m)	No. of oscillation
I	300	1.57	-	1.58	0.05	1
II		1.17	-	0.51	0.003	1
III		0.42	0.67	2.1	0.003	24
I	500	2.33	-	1.20	0.003	1
II		1.52	-	0.09	0.003	1
III		0.25	0.75	0.37	0.004	26
I	700	2.55	-	1.59	0.004	1
II		1.72	-	0.37	0.003	1
III		0.48	0.88	4.93	0.004	23

All data needed of these variables are collected and analyzed by evaluating settling time, decay ratio, integral absolute error (IAE), distance first peak to set point and number of oscillation analysis to identify the variables will give contribution to the performance of system in the presence of load disturbance test is applied at early stage and tuned at set point 300mm, 500mm and 700mm.

Therefore, the best performance of tuning parameter of Fuzzy Logic Control at set point 500mm in which the best condition to be used in the boiler level control indicates to the fast response of settling time of set point, no decay ratio, no overshoot, and minimum percentage of integral absolute error in this experiment.

IV. CONCLUSION

In conclusion, both objectives of the study which are to determine the best input and output parameter Fuzzy Logic Controller and to study the performance of level process using Fuzzy Logic System were achieved. Based on the simulation, tuning parameter of Fuzzy Logic Control at set point 500mm is the best performance and suitable output to be used in the boiler level control due to the fast response of settling time, no decay ratio, no overshoot, and minimum percentage of integral absolute error. Therefore a study should be conducted to improve test even more, it is advisable to calculate the Integral Absolute Error (IAE) by using Simulink itself, the result obtain is more accurate than calculate manual IAE. Besides, it is also recommended that in the future study to reduce the settling time, try to use other type of control strategies such as feed forward, cascade, feedback feed forward and others.

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