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SIMULATION WATER LEVEL CONTROL IN THE STEAM DRUM OF STEAM POWER PLANT'S BOILER SYSTEM USING A ROBUST SELF-TUNING SCHEME FOR PID-TYPE FUZZY

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***Abstract* — The water level in the steam drum needs to be kept constant at a certain point. Therefore, control is needed for the flow rate of incoming water feedwater to adjust to the disruption of the steam flow rate that comes out. The size of the steam flow rate that comes out depends on the load demand. If the demand for loads is high and fluctuations, then the water level in the steam drum will be more difficult. The PID type fuzzy logic controller with a robust self-tuning scheme will be implemented in the water level regulation system in the steam drum. In the three-element control scheme, when given a high load of 700 MW the system produces an error deviation of 15.69 mm peak against the set point. This value is smaller than the single-element control scheme by producing an error deviation of 18.5 mm against the set point. However, when given a set point change of 40 mm the three-element control scheme produced a response of 16.82 mm peak error error to the set point. This value is greater than the system response with the single-element control scheme which only produces an error deviation of 3.91 mm peak against the set point.**

Keywords* — *Fuzzy-PID, robust self-tuning scheme, steam drum.

I. INTRODUCTION

The PLTU is a generator that relies on kinetic energy from steam to produce electricity. The process of converting water into steam as shown in Fig. 1 is carried out by a boiler system that provides heat energy from the combustion process [1]. The steam produced by the boiler will be controlled by a valve so that the turbine rotation in the generator is maintained constant at a value of 50 + 0.5 Hz for changes in fluctuating loads [2].

In the boiler system there are components of the steam drum which play a role in accommodating and separating the mixture between water and steam. The water level in the steam drum also needs to be kept constant against the steam coming out of the steam drum. The amount of steam flowing out of the steam drum varies depending on the electrical load. While the water flow rate that enters the steam drum can be adjusted through setting the BFPT rotation speed (Feedwater Pump Turbine Boiler). Based on this, a regulatory system is needed so that the water level of the steam drum is in accordance with the normal water level (NWL) condition.

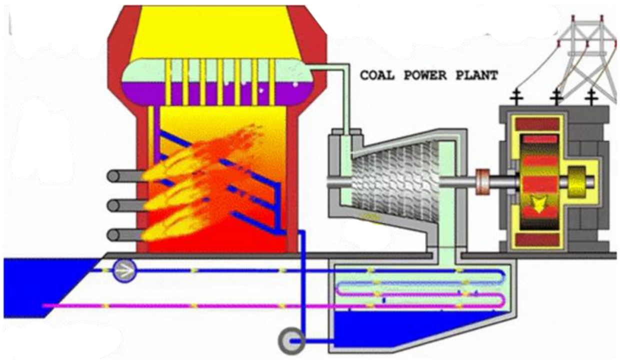


Fig. 1. Steam power plant work system [16]

Control of water level in the steam drum is one of several conditions that need to be maintained to avoid MFT or trip. The control method used in this study is heuristic control with fuzzy logic that is more easily applied to complex systems. In general, the steam drum arrangement can be done with a single element control scheme which is usually applied to loads <30% and the starting or three element control process which is more complex than single element control for loads> 30% when operating conditions.

The fuzzy logic controller scheme that will be applied in this study is using a robust self-tuning scheme [3]. The control system is expected to produce a system response that is more resistant to interference. The control scheme has an adaptation gain for integrators who can avoid system wind-ups due to actuator saturation. While for the type of fuzzy logic controller applied in this study is the control of fuzzy logic with the PID type [4].

II. MODELLING SYSTEM

A. Modelling actuator of BFPT

The model of BFPT is brought closer to the first order equation model with input is feedwater demand which is the demand for the rate of feedwater flow and output is the flow rate of the feedwater produced, with saturated value is 0-

2188 t/h. Using the least square regression method with the same sampling time so that equation (1) is obtained.

$$\frac{M_{fw}(z)}{M_{fwd}(z)} = \frac{-0{,}014z + 0{,}022}{0{,}988z - 0{,}983} \quad (1)$$

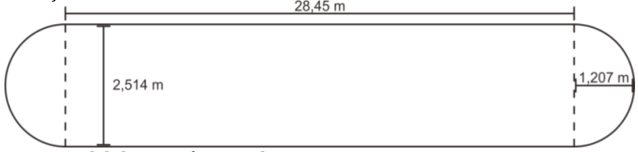


Fig. 2. Model design of steam drum

B. Relation between Load and Steam Flow Rate

Steam flow (M_{st}) as disturbance, by using the least square regression method with a static equation, the bias parameter value is 406.586 and the slope or gradient parameter is 1.85. So that the equation of relationship between load and steam flow rate can be expressed in equation (2), with *load* in MW.

$$M_{st}(k) = 406{,}586 + 1{,}85. Load(k) \quad (2)$$

C. Modelling Plant of Steam Drum

The physical design model of the steam drum is depicted as in Fig. 2, with the value of the spherical radius of the steam drum (r) being 1.207 m and the tube width on the steam drum being 28.45 m. The modeling for obtaining the input-output relationship in the steam drum is based on the law of the equilibrium between the incoming water and the steam coming out on the steam drum.

So that the transfer function of the steam drum model in the 's' frequency domain through Laplace transform for water level (H) is stated as in equation (3) with A is surface area of water (m^2), ρ is density (kg/m^3), and M is mass flow (t/h).

$$\frac{H(s)}{M_{fw}(s) - M_{st}(s)} = \frac{1}{A.(\rho_{fw} + \rho_{st}).s} \quad (3)$$

With the parameter data of the width and radius of the steam drum, it can be estimated the surface area of the water in the steam drum when it is at the NWL point. Then the model in the 's' domain will be transformed into the domain 'z' with a sampling time of 0.1 seconds using the standard tilinine biliner transformation method. The result of the transfer function in the 'z' domain is stated in equation (4).

$$\frac{H(z)}{M_{fw}(z) - M_{st}(z)} = \frac{2{,}29z - 2{,}29}{1 - z} \quad (4)$$

III. System Planning

The design of PID type fuzzy logic controller in this study uses a robust self-tunning scheme. The scheme basically consists of two main components, including a controller that produces a control signal and gain tuning mechanism as a gain adaptation in the form of a scaling factor (α) represented in a block diagram as shown in Fig3.

A. Fuzzification Unit

Before the fuzzification process, as shown in Fig. 4, the normalization process for fuzzification unit will be carried out on error signals and deltas according to the fuzzification range ranging from -3 to 3.

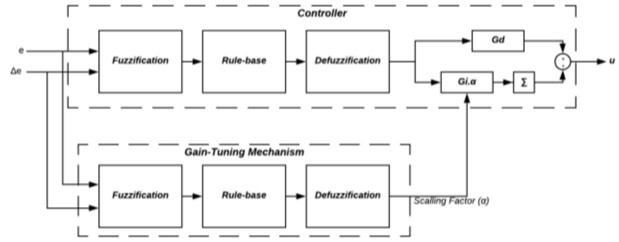


Fig. 3. Fuzzy-PID robust-self tuning controller

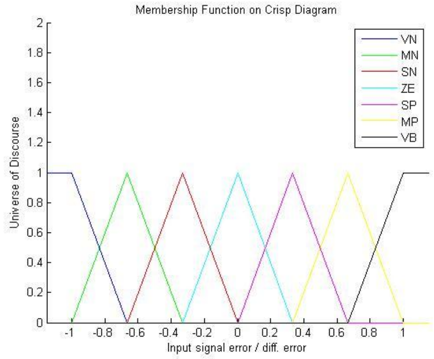


Fig. 4. Membership function of error and diff. error signals

The single-element control normalization process for error signals is based on the working range of the steam drum level, which is -350 mm to 350 mm, so the scaling value is 3/700. As for the delta-error signal, the normalization value is set to 3/10,0118504.

Likewise on Scalling Factor or Gain-tuning Mechanism for error signals and delta errors, the fuzzification process will be defined with a membership function that exactly matches the fuzzification process on the Controller.

B. Designing the Rule Base

After the fuzzification process, rule-base is determined for each of the functions of the membership of the Controller and Scaling Factor or Gain-Tuning Mechanism. The rule-base design adapts to the number of membership functions for the fuzzification and defuzzification process for Mamdani.

The design is determined by seven membership functions (mf1) which include Very Negative (VN), Medium Negative (MN), Small Negative (SN), Zero Equals (ZE), Small Positive (SP), Medium Positive (MP), and Very Positive (VP). Each relations of membership functions can be stated in the Mack Vicar table in Table 1.

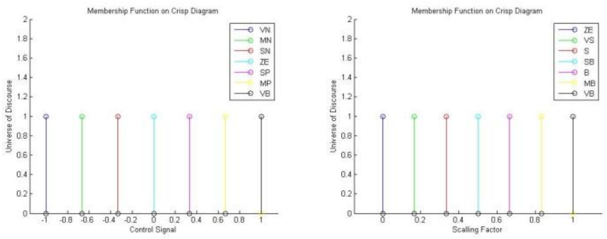
Whereas in the Gain-tuning Mechanism or Scalling Factor, rule design is defined by 7 membership functions (mf2) which include Zero Equals (ZE), Very Small (VS), Small (S), Small Big (SB), Big (B), Medium Big (MB), Very Big (VB). Each relationship of membership functions can be stated in the Mack Vicar table in Table 2.

Table 1. Rule-base for Controller

Δe \ e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	VN	VN	VN	MN	SN	SN	ZE
NM	VN	MN	MN	MN	SN	ZE	SP
NS	VN	MN	SN	SN	ZE	SP	MP
ZE	VN	MN	SN	ZE	SP	MP	VP
PS	MN	SN	ZE	SP	SP	MP	VP
PM	SN	ZE	SP	MP	MP	MP	VP
PB	ZE	SP	SP	MP	VP	VP	VP

TABEL 2. RULE-BASE FOR GAIN-TUNING MECHANISM

Δe \ e	NB	NM	NS	ZE	PS	PM	PB
NB	VB	VB	VB	B	SB	S	ZE
NM	VB	VB	B	B	MB	S	VS
NS	VB	MB	B	VB	VS	S	VS
ZE	S	SB	MB	ZE	MB	SB	S
PS	VS	S	VS	VB	B	MB	VB
PM	VS	S	MB	B	B	VB	VB
PB	ZE	S	SB	B	VB	VB	VB



(a) (b)

Fig. 5. Singleton's defuzzification for (a) controller (b) scalling-factor

C. Mamdani's Inference

After that, inference is done, which in this case can be done by several methods. In setting this level, both the Controller and the Gain-tuning Mechanism or Scaling Factor inference method used both are the minimum of maximum (MOM), which is expressed in equation (5).

$$U_x = max\left(U_x, min(mf_1, mf_2)\right) \quad (5)$$

The ux variable states the results of inference, mf1 and mf2 are the values of each membership function for i = 1,2, ... (number of error membership functions) and j = 1,2, ... (number of membership functions delta error).

D. Defuzzifikasi Unit

At this stage the results of reasoning values will be stated in the crisp diagram. Both the Controller and the Gain-tuning Mechanism, both of which use the singleton type membership function which is represented in the crisp diagram of Fig. 5(a) and Fig. 5(b).

where x * is the result or output value of the defuzzification process, n is the number of sample elements, xi is the sample element and µi states the membership function value.

E. System's Specifications

System specifications describe the target or the results we want for the system as in Table 3. So that the controller design that is done is intended so that the system meets the response criteria in accordance with predetermined specifications.

The system of regulating the water level in the steam drum is observed to set the system criteria for two conditions, which include the criteria for system response to changes in set-point of 40 mm and also to changes in electrical load disturbances ranging from no load, 400MW to 700MW.

IV. DESIGN FOR STEAM POWER PLANT'S SIMULATOR

Communication between HMIs with each different PC represents the working principle of the Client-Server distribution structure, with HMI-I as a client and HMI-II as a server. So in the HMI-I both set-point and output are read / write, while the HMI-II set-point is read / write while the output is read as found in Fig. 6.

TABLE 3. SYSTEMS SPECIFICATIONS

Water level	Between -361 mm and 254 mm
Settling-time	< 38,7 second

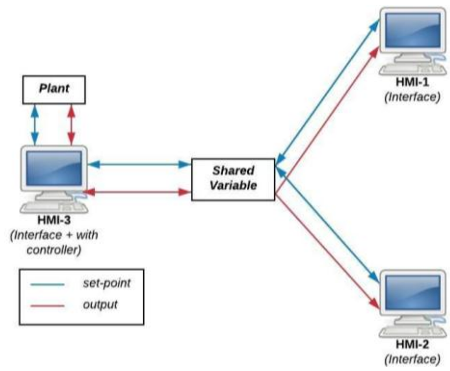


Fig. 6. Data exchange schemes with shared variables

The Overview view in Fig. 7 displays system information in general. The information includes system response graphs, controller parameters, control mode selector, selector for single-element control or three element control, load demand, set point level, percent valve for feedwater and steam, shrink / swell, fluctuating load, and blowdown as input . Whereas the output includes the percent valve condition, pressure and water level on the steam drum, boiler trip indicators, and the system response graph.

Then the view of Steam Drum in Fig. 8 displays information related to the variables that are specifically found in the steam drum along with their physical images with the aim that information is easier to receive. Then the last panel display is Controller Fig. 9 which displays Fuzzy logic controller parameters. These parameters can be changed or re-tuned as needed directly by the operator and adjust to the conditions of the system.

Then for the block diagram as a program on the Simulator system, the PLTU is designed with the main VI, with several Sub-VI as shown in Fig. 10.

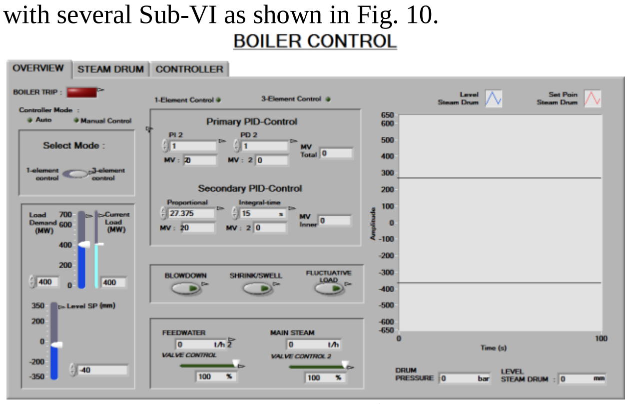


Fig. 7. HMI display in the Overview's panel

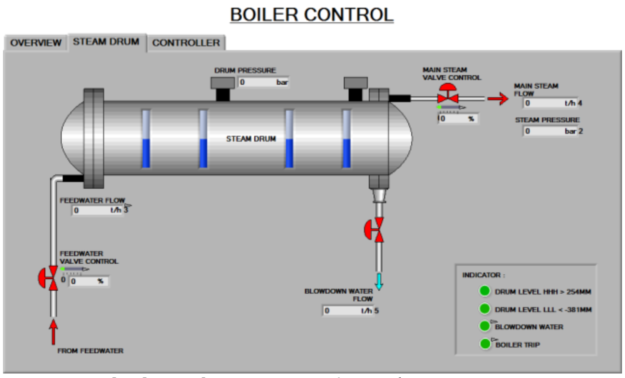


Fig. 8. HMI display in the Steam Drum's panel

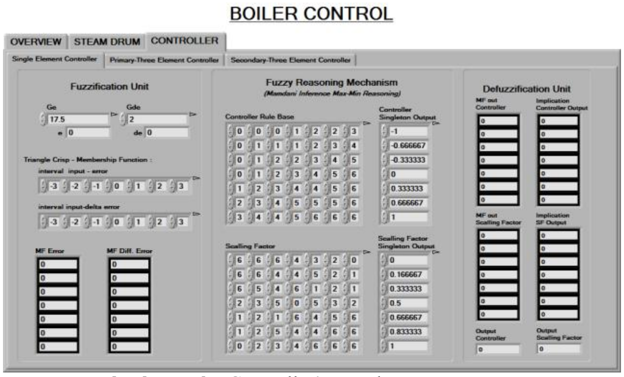


Fig. 9. HMI display in the Controller's panel

When the boiler trip, the program is designed so that the control mode switches to manual control and the valve from the feedwater pipe and steam becomes closed (0%) to avoid offset levels that are too large. The valve arrangement diagram scheme to be closed when a trip occurs is as shown in Fig. 11. Then the scheme with the same design will be applied to the valve in the steam pipe.

In addition, there are also many other program models as shown in Appendix 13, including panels that automatically move according to the control mode used, synchronizing values between P and KP, Ti and Ki, Td and Kd, and the corresponding configuration so that each set-points on each HMI-1, HMI-2, and HMI-3 can follow changes to the set values without causing crashes from exchanging data.

V. RESULTS AND ANALYSIS

Testing of PID-type fuzzy logic controller with robust self-tuning scheme will be applied to single-element control and three-element control. Testing is done by giving a change of 40 mm set-point with a load of 400 MW and also

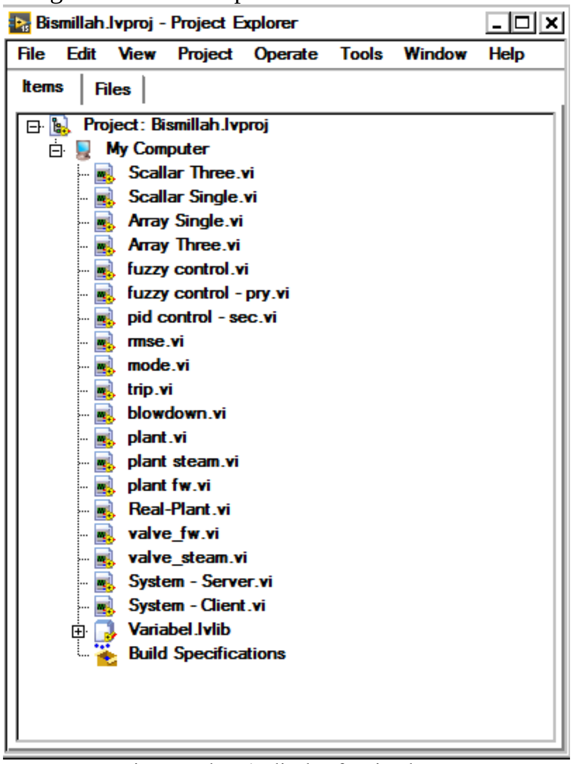


Fig. 10 Projects explorer's display for simulator

Fig. 11. The valve design is closed when the boiler is trip

observed the effects of disturbance on the system by increasing the power load to 700MW.

A. *Fuzzy*-PID *Robust Self-tuning*

The results of the system response to each of the larger PI parameter values are as shown in Fig. 12. The system response for the three PI parameter values does not have a significant difference, more clearly can be seen in Table 4. If seen based on the system response characteristics data, the higher PI value can produce a larger system oscillation.

Also, the resulting steady-state error is smaller as in the PI parameter value of 0.1 and 0.5, which has a slightly better system response criterion. However, if the PI parameter value is too high, the resulting oscillation, undershoot, and steady-state error will also increase. So that PI values are able to produce the best system response is 0.5 based on the system performance index value (J) which is also produced.

B. *Three-element Control Scheme*

The results of the tuning are then tested on the system, based on Fig. 13, the system results have a fast transient response, only a large overshoot with a value of 63.92% is still produced by the PI controller while the P controller still produces a steady-state error despite its value small which is only 3.43%.

After obtaining the tuned PID parameter for controlling the inner-loop then it is then implemented in the system as a whole for the three-element control. Because the integrator has been obtained on the outer-loop and the system is already type-1, then controlling for inner-loop is enough to use the P controller only from tuning.

This system is tested with the control parameter value on the outer loop with a PI of 0.06 and the most suitable PD value is sought. The result is a system response as shown in Fig. 13. It can be concluded that the three-element control is able to reduce wind-up better than single-element control so as to produce a smaller undershoot when given a set-point down with a nominal load.

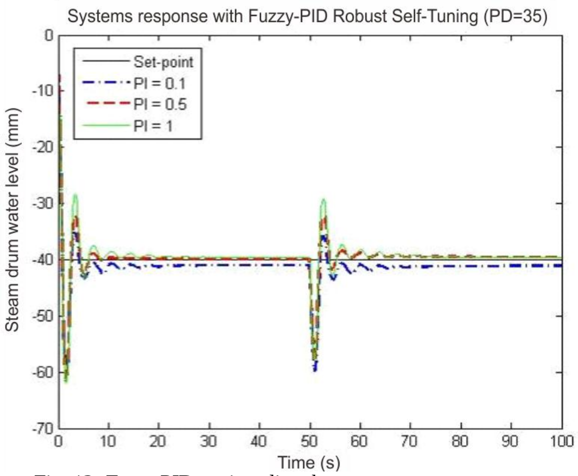


Fig. 12. *Fuzzy*-PID against disturbance

TABLE 4. SYSTEM CRITERIA WITH FUZZY-PID

Systems Criteria	PI = 0,1	PI = 0,5	PI = 1
Water level's value after 50 second	0,96 mm	0,14 mm	0,33 mm
Water level's value after100 second	1,11 mm	0,44 mm	0,38 mm
Pertubation peak (change of set-point and 400MW load)	19,77 mm	20,66 mm	20,08 mm
Pertubation peak (700MW load)	21,14 mm	21,06 mm	21,11 mm
IAE	1.920,8	1.225,9	1.527,7
ISE	15.103,8	13.738,9	15.367,7
J	3.239,1	2.477,2	2.911,7

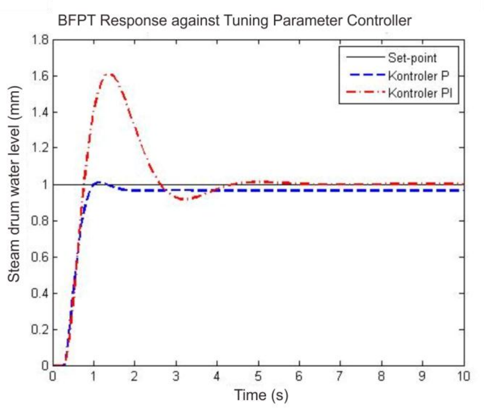


Fig. 13. Inner-loop controller on the actuator

While the resulting peak differences are not significant, with PD parameters equal to 1 having the smallest value of the others. From the steady-state error generated, all three have produced fairly small values as shown in Table 5.

Overall, systems based on the resulting response criteria, the PD controller parameter with value 1 produces the best system response among the three as shown in Fig. 14. However, the PD parameter of 1 produces oscillation around its steady state value, so that in the parameter values the system stability is degraded.

After testing the system with the set-point down with a nominal load, then the system is tested with a set-point up of 40 mm with a nominal load. Then just as before after 50 seconds the system will be given a maximum load. The resulting system response is as in Fig. 15, which shows that single-element control is capable of producing a much better response than the three-element control for changes in set-point.

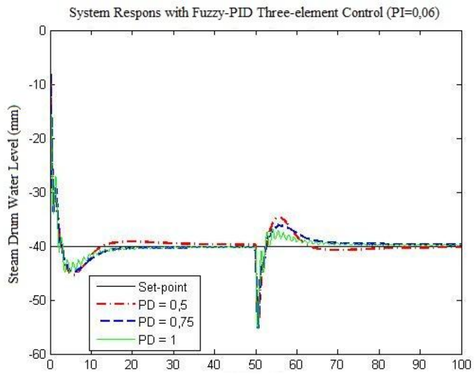


Fig. 14. System response with three-element control

TABLE 5. SYSTEM CRITERIA WITH THREE-ELEMENT CONTROL

Systems Criteria	PD = 0,5	PD = 0,75	PD = 1
IAE	1.387,8	1.305,6	1.057,2
ISE	9.356,0	8.737,7	7.814,5
J	2.184,6	2.048,8	1.732,9

This shows that single-element control is used during the starting process, where at that time there are many set-point changes in the system. Overall the system criteria with changes in set-point rise can be seen in Table 6.

C. System Testing for Random Load Changes

Testing is done by comparing the response of the two schemes between single-element control with three-element control for the presence of a load or random interference. The interference given is a random value load with ranges from 400 MW to 700 MW to be given to both control schemes. The controller scheme used in the single-element control is the PID type fuzzy logic controller with a robust self-tuning scheme, as well as the outer-loop controller in the three-element control while the conventional P-loop controller is used for the inner-loop. As in the previous test, the system was given a set-point down by 40 mm with a given random value load. The controller parameters used were taken from the best value based on the results of previous analyzes. The results of the test obtained a system response as shown in Fig. 15.

The three-element control scheme is not able to produce a good response to changes in set-points as in the previous test. On the other hand, Fig. 16 shows that in the single-element control scheme it is not able to maintain its steady state value well in fluctuating (random) load conditions, while in the three-element scheme the system control is able to reduce interference better with the resulting deviation tends to be smaller . This also proves that the three-element control has a faster response.

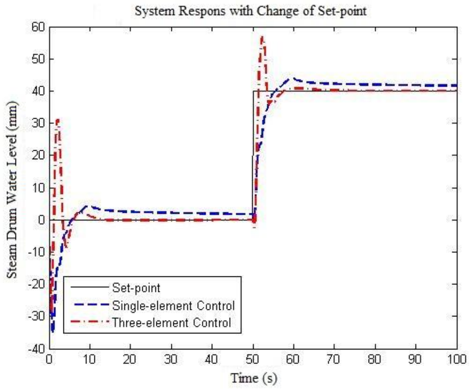


Fig. 15. Three-element control's response with change of set-point

TABLE 6. SYSTEMS CRITERIA WITH THREE-ELEMENT CONTROL

Systems Criteria	Single-element Control	Three-element Control
Water level's value after 50 second	0,66 mm	0,04 mm
Water level's value after100 second	0,46 mm	0,06 mm
Settling-time (change of set-point and 400 MW load)	2,8 second	2,85 second
Settling-time (700 MW load)	2,55 second	2,55 second
Pertubation peak (change of set-point and 400 MW load)	12,34 mm	6,79 mm
Pertubation peak (700 MW load)	18,5 mm	15,69 mm
IAE	1.252,6	734,7113
ISE	9.250,2	7.529,4
J	2.052,4	1.414,2

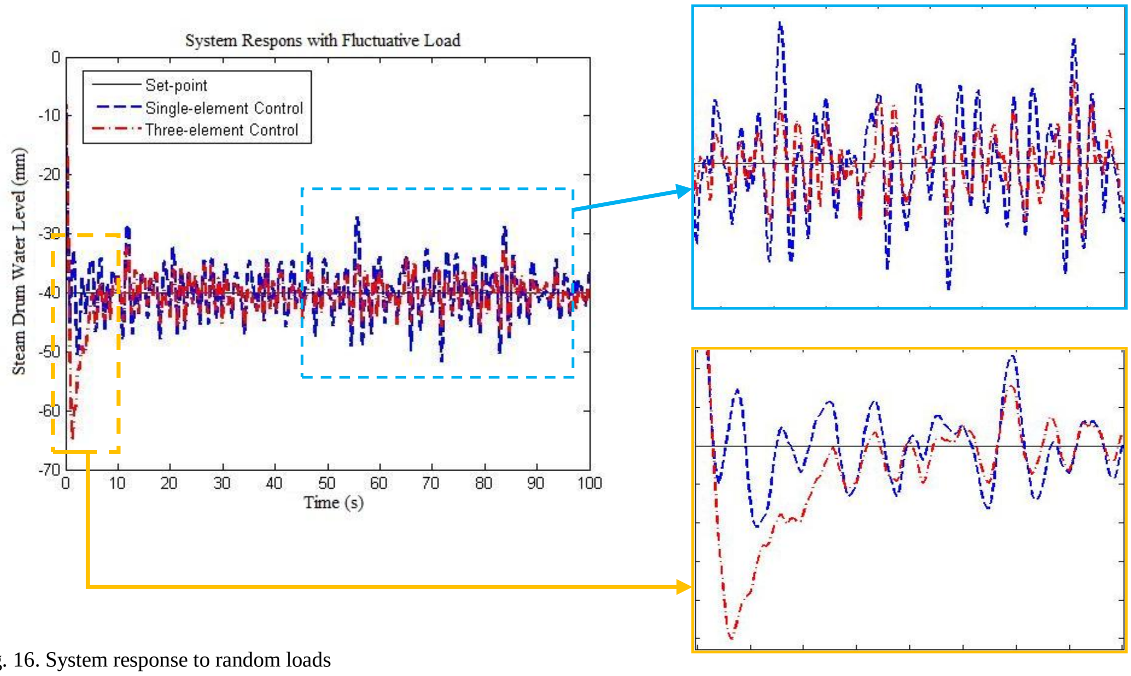


Fig. 16. System response to random loads

VI. CONCLUSION

The use of PID-type fuzzy logic controllers with robust self-tuning schemes can complement the shortcomings of PI-type and PD-type fuzzy logic controls by producing 17.09 mm peaks at maximum load and steady-state error of 0.09 mm.

The three-element control control scheme is able to produce a system response that is more resistant to interference than the system when using single-element control schemes. The three-element control scheme is able to maintain its steady state condition by producing pertubation peaks of 15.69 mm for maximum load, where the value is smaller than the single element control which results in a peak peak of 18.5 mm against maximum load.

For the starting process in the boiler system, single-element control is capable of producing a better response compared to the three-element control scheme. Single-element control produces 3.91 mm peak against changes in set-point up with nominal load, where the value is much better than when using the three-element control scheme which produces a value of 16.82 mm.

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