Improved Inverse Response of Boiler Drum Level using Fuzzy Self Adaptive PID Controller

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***Abstract*— The paper discuss, Inverse response of the boiler drum water level. Steam drum level is one of the major causes of boiler trips and downtime, affected by the phenomena of swell and shrink; it is a difficult parameter to control accurately. The Conventional PID cannot give satisfactory result for boiler drum level. In order to overcome above drawback we have design Self adaptive fuzzy PID controller for boiler drum level control. From simulation, the performance of Self adaptive fuzzy PID controller is better than IMC controller which help to reduce undershoot & overshoot. MATLAB simulink tool is used to simulate self adaptive Fuzzy-PID and IMC control system.**

***Keywords*— Inverse Response, IMC Controller, Fuzzy Control, Fuzzy Adaptive PID.**

I. Introduction

Drum level is one of the most important and critical control parameter for the boiler safety and stable operation. The inverse response is most challenging task for all control engineers. There are mainly two reasons of Inverse response.

1. When the response is in opposite direction with respect to the ultimate steady state value.
2. Presence of right half plane zeros for any other reason as well.

The examples where this process is used are like in distillation columns, drum boiler, etc.

The boiler operation is based on the demand of load in stem flow. Steam demand is depends on the downstream process via downstream equipment like turbine, Auxiliary steam for process etc. If the demand of steam increase or decreases then drum pressure will get affected due to sudden change in the load as well as steam drum level increase and decrease rapidly due to the change in pressure, it will change both density and boiling point of water in the circuit. As the process of increase and decrease in water level are usually called as swell and shrink reaction [1].

If the process load demand suddenly reduced to unexpected reason then the pressure of drum will be increase, caused by the back pressure generated in the steam line. The effect of increased pressure will cause to operate drum level to shrink initially and the drum level increase because of the inlet flow is more than outflow and vise versa if steam outlet demand increase suddenly then drum level will swell. To control drum level is very difficult in both Shrink and swell cases. Theoretical researches of boiler drum level carry out many results considering conventional PID controller.

In this paper, Internal Model Control (IMC) and Fuzzy Controller is used for inverse response of boiler drum level. The nice thing about the Internal Model Control (IMC) procedure is that it results in a Controller with a single tuning parameter, the IMC filters (λ) [2]. For a system which is "minimum phase", λ is equivalent to a closed-loop time constant (the "speed of response" of the closed-loop system). Although the IMC procedure is clear and IMC is easily implemented [3].

One of the smart control model method is Fuzzy. The fuzzy is basic set of rules which is based on system error and change in error which expert advice into automatic control condition for self adaptive controller. Fuzzy represents a sequence of control mechanism to adjust the effect of certain system stimulation. It reflects the expert conditions in to appropriate control design [4].

II. FUZZY CONTROLLER

Fuzzy inference systems (FIS) which defines relationship between response and stimulation, its also based on fuzzy set of theory and its logic. FIS mapping is done from input to output space. FIS allows used to construct structure for generating response of output or input. As FIS are rule-based systems, it defines relation between input of system and output as expected [5].FIS system is also named as Fuzzy knowledge based system. Fuzzy Logic Toolbox greatly amplifies the power of human reasoning. Further amplification results from the use of MATLAB and graphical user interfaces. Block diagram of fuzzy controller has shown below in fig. 1.

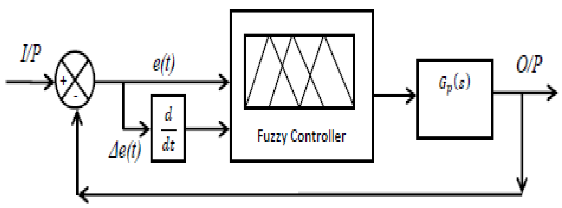

Fig. 1 Fuzzy logic controller basic Block digram.

In mamdani based fuzzy inference system, inputs and outputs has an "If-Then" rules. In this paper, we are using boiler example, we are considering two input variable system (Error and Change in error) and three output variable system. (Kp, Ki and Kd)[9]. The mamdani type FIS editor for two-input and three-output system has been shown in fig 2.

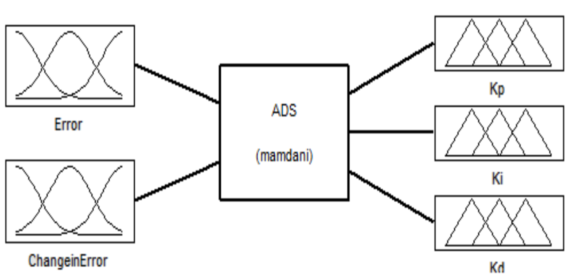

Fig. 2 Two-input and three-output system of mamdani type FIS editor.

The fuzzy adaptive PID controller consists two parts, one is fuzzy Interpretation controller and another is adaptive PID controller [6]. The root of fuzzy controller it contains fuzzification, repository, fuzzy inference, Defuzzification and input/output quantification and so on. Fuzzy logic is a set of rules rule which can map a space-input to another space-output. The set of rules are map based on the expert knowledge [7].

For a given fuzzy logic controller or system we need to mention the number of inputs and number of outputs. Each and every input and output is to be defined by some particular membership functions. We need to develop the appropriate rules using experience and knowledge. We had consider below Linguistic Variables for Fuzzy logic controller.

Table. 1 Linguistic variables for fuzzy logic controller.

NB -	Negative Big
NM	Negative Medium
NS	Negative Small
ZO	Zero
PS	Positive Small
PM	Positive Medium
PB	Positive Big

According to the precision and control requirements, it is appropriate that 7 levels are usually selected [10]. The Tables 2 to 4 is showing the fuzzy control rules of Kp. Ki, Kd and figure 3 to 5 showing the membership function curve for Error and change in error [7], and Kp, Ki, Kd. In accordance with demand and characteristic of drum water level, selected three impulse conversion fraction. [11].

Table. 2 Set of fuzzy rules for Kp.

Ec	E						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table. 3 Set of fuzzy rules for Ki.

Ec	E						
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table .4 Set of fuzzy rules for Kd.

Ec	E						
	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PS	PS	PS	PB

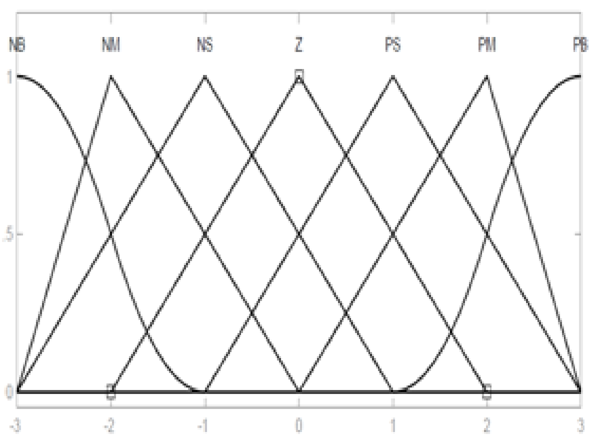

Fig. 3 Membership function curve of Error (E), Change in Error (Ec)

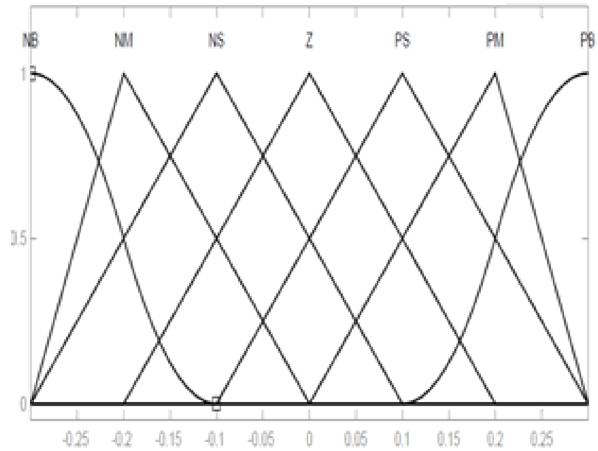

Fig. 4 Membership function of Kp, Kd

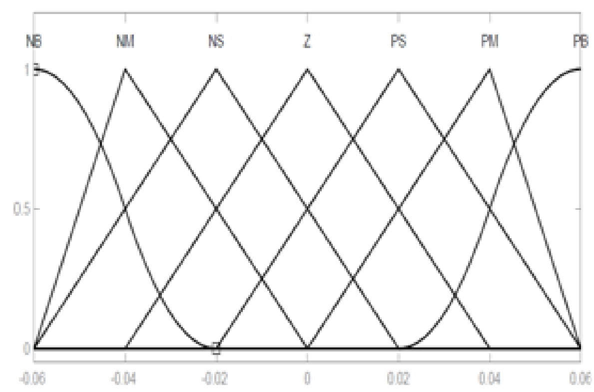

Fig. 5 Membership function of Ki.

III SIMULATION RESULT

We obtained results of IMC controller and self adaptive fuzzy in Matlab simulink for Inverse response of Boiler drum level. In this paper, we had consider following process transfer function and disturbance.

Process Transfer function

$$Gd(s) = \frac{-0.25S+0.25}{0.3S^3+2.15S^2+S}$$

Process disturbance

$$Gd(s) = \frac{0.25S-0.25}{2S^2+S}$$

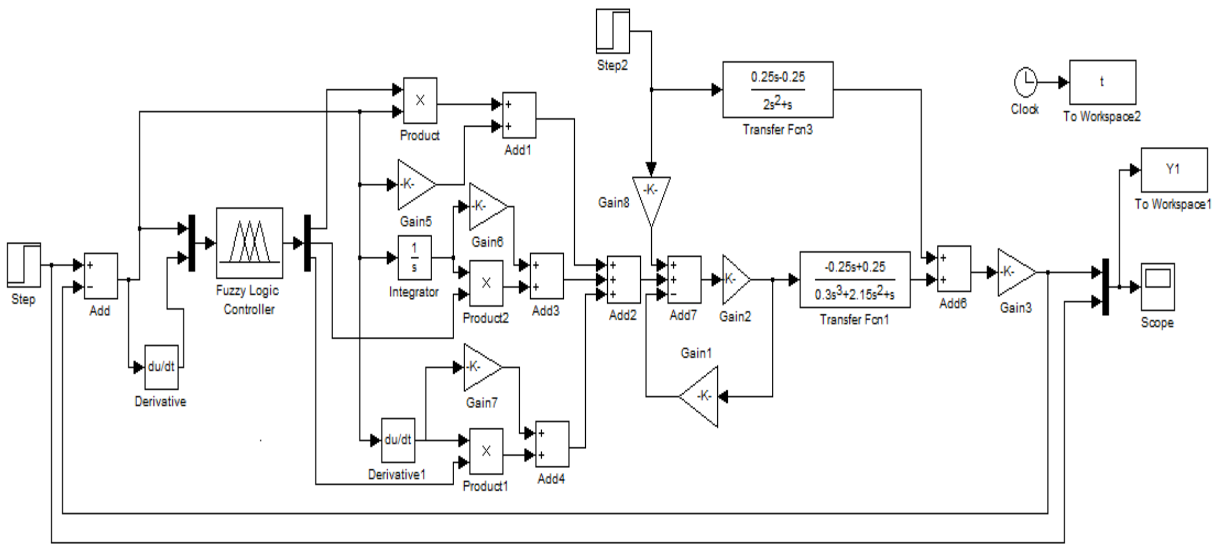

Fig. 6 Fuzzy Self Adaptive PID Controller MATLAB Simulink Model.

The IMC controller output is calculated as,

$$Gc\ (s) = \frac{1.2S^2+8.6S+4}{S^3+3S+4}$$

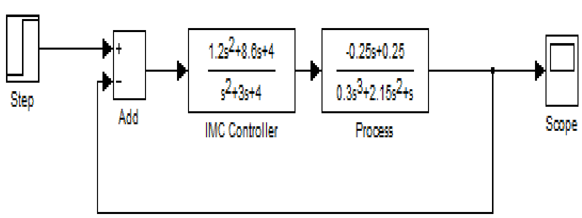

Fig. 7 IMC MATLAB Simulink Model.

Using described simulink models for steam boiler drum level we get result of output response to a step response in drum level IMC and self adaptive fuzzy controller without disturbances are shown in Fig. 8 and accordingly further Comparing Time domain specifications results are shown in Table : 5

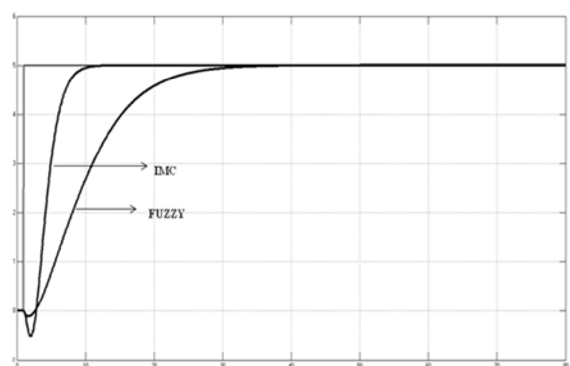

Fig. 8 Simulink result without disturbance.

Table. 5 Comparing Time domain specifications without disturbances

Sr. No	Time domain Specification	IMC	Self Adaptive Fuzzy
1	Rise Time	3.923	14.84
2	Settling Time	9.135	27.50
5	Overshoot	0	0
6	Undershoot	10.35	2.180

using described simulink models for steam boiler drum level we get result of output response to a step response in drum level IMC and self adaptive fuzzy controller with disturbances are shown in Fig. 9 and accordingly further Comparing Time domain specifications results are shown in Table 6.

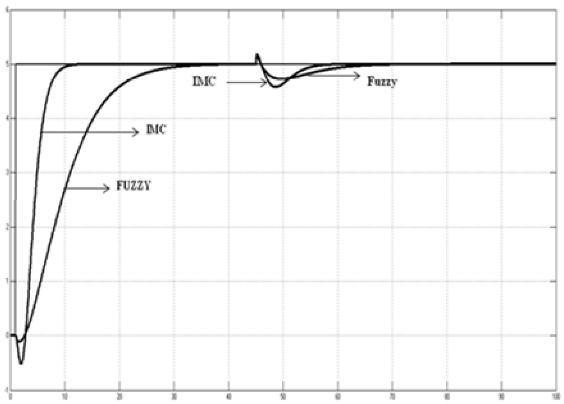

Fig. 9 Simulink result with disturbance.

Table. 6 Comparing Time domain specifications with disturbances

Sr. No.	Time domain Specification	IMC	Self Adaptive Fuzzy
1	Rise Time	03.923	14.845
2	Settling Time	53.561	58.354
5	Overshoot	03.614	02.353
6	Undershoot	10.358	02.180

IV. CONCUSION

In this paper, Boiler drum level inverse response case study has been considered. From Simulink results and time domain specifications, it is observed that IMC controller shows better rise time and less settling time. However, IMC response has high overshoot and undershoots. In this paper, to overcome inverse response of system we have design Self adaptive fuzzy controller. Self adaptive fuzzy controller gives better performance in terms of overshoot and undershoots. However, sluggish response results in an increase in rise time and settling time. The better response for inverse response is achieved through self adaptive fuzzy controller.

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