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Fuzzy Logic based Boiler drum level control with GUI

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R. R. Sonawane*,P. G. Medewar† R. K. Munje‡
*K. V. N. Naik Institute of Engineering, Education & Research, Nashik-422003, India.
†K. K. Wagh Institute of Engineering Education & Research, Nashik-422003, India.
E-mail: *sonawanerupali54@gmail.com, †medewar.prashant@gmail.com, ‡ravimunje@yahoo.co.in

Abstract— **The water level in boiler drum is a nonlinear system. Depending on the mathematical modelling of boiler drum level system, the fuzzy controller is used for designing a control system. A boiler drum water level system consists of three measurement signals drum level, water and steam flow. The system response using fuzzy logic in mamdani and sugeno FIS is observed in GUI in MATLAB and compared with PID controller. A sugeno FIS is more flexible than mamdani FIS. It is observed that fuzzy logic improves the static the time response of drum level control.**

***Keywords*—Boiler Drum Level Control, Graphical User Interface, Fuzzy Logic Controller, Mamdani and Sugeno Fuzzy Inference Systems, Proportional-Integral-Derivative Controller**

I. INTRODUCTION

Fuzzy logic controllers are widely used in process control industries to control level, flow and quality of liquid or chemicals. The pioneering researchers of fuzzy control are mamdani and zadeh's and their system analysis based on fuzzy theory sets[1][2].

In process plant, many loops requires boiling water and also wants the steam supply constantly. This supply to the plant is provided from the boiler. Hence it necessary to control the water level in boiler drum at a given point at constant steam supply. When this level is decreased, it will cause to overheat the boiler tubes, due to this tubes may get damaged or failure. And when this level is increased, then the boiler efficiency will get reduced. Therefore the boiler drum level requires proper designing of controller to achieve the good control over the problem[3].

A boiler drum is having phenomenon of shrink and swell effect. When the level in the drum is increases then it will cause the 'swell' effect. Because it will cause the sudden increase in drum level even when the extra water is not added. And the decrease in boiler drum level will cause the 'shrink' effect.[4].

A boiler drum level is a multiple input-output system. The control method for this system is to use a PID controller but this controller is having some drawbacks like it requires more settling time and rise time, large overshoot and errors. This drawback will overcome by fuzzy logic controller because boiler drum level system is a nonlinear process. This controller will gives much satisfactory response as that of PID controller[5]. Most of the work is done in mamdani FIS using fuzzy logic by the various researchers, hence purpose of this paper is to do work on sugeno FIS.

The objective of this paper is to control the drum level of boiler as per requirement. For this a dynamic mathematical model is obtained and the response of a system is observed using fuzzy logic in mamdani and sugeno FIS, PID controller in MATLAB GUI. A paper is organized in such a way that section II represents mathematical modelling of boiler drum level, section III gives introduction about fuzzy logic control, section IV represents the controller design of a given system. section V represents the observations of a system response and section VI gives the conclusion about the response of a system.

II. ELEMENTS OF BOILER DRUM LEVEL

A boiler drum level system consists of three major elements like drum water level, steam flow and feedwater valve for the supply of water into the drum. The main aim of this system is to maintain the level when there is any changes in water supply or steam flow[6].

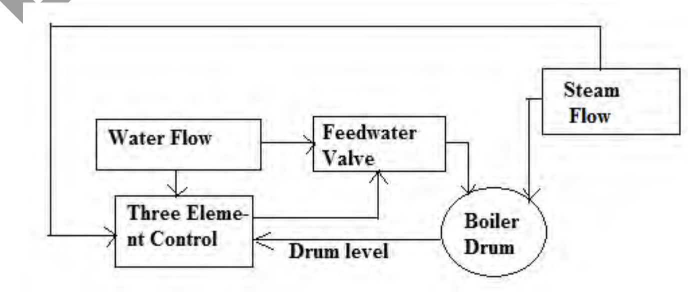

Fig. 1. Basic elements of drum level system[6]

A. DYNAMIC BEHAVIOUR OF A BOILER DRUM LEVEL

The dynamic characteristics includes the water flow and steam flow, and their effects mathematically expressed as[7],

$$T_1T_2\frac{d^2h}{d^2t}+T_1\frac{dh}{dt}=(T_w\frac{du_w}{dt}+K_wU_w)-(T_D\frac{du_D}{dt}+K_DU_D) \quad (1)$$

where h is height of boiler drum, T_w and T_D are time constants of water and steam flow respectively, K_D and K_w are magnification steam flow and water flow respectively. T_1 and T_2 are time constants.

The water and steam flow are the disturbances of the system due to which level in drum will get changed. The drum level under the effect of water supply is expressed as:

$$T_1T_2\frac{d^2h}{d^2t}+T_1\frac{dh}{dt}=(T_w\frac{du_w}{dt}+K_wU_w) \quad (2)$$

Taking Laplace transform to get relation between water flow and drum level,

$$W(s) = \frac{h(s)}{U_w(s)}=\frac{T_ws+K_w}{T_1s(T_2s+1)} \quad (3)$$

The drum level with disturbances can be evaluated as,

$$T_1T_2\frac{d^2h}{d^2t}+T_1\frac{dh}{dt} = -(T_D\frac{du_D}{dt}+K_DU_D) \quad (4)$$

The transfer function for drum level under the action of steam flow is,

$$W(s) = \frac{h(s)}{U_D(s)}=-\frac{T_Ds+K_D}{T_1s(T_2s+1)} \quad (5)$$

For our system, the water flow and stem flow transfer functions are,

$$G_w(s) = \frac{0.056}{s(35s+1)}$$

$$G_D(s) = \frac{2.045s-0.068}{s(18s+1)}$$

and valve transfer function is

$$G_z(s) = \frac{3.5}{0.39s+1} \quad (6)$$

III. FUZZY LOGIC CONTROLLER

Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human actions. Fuzzy techniques have been successfully used in control in several fields. Fuzzy logic gives approximate reasoning instead of exact. Fuzzy logic takes the inputs in the form of a crisp value and converts that into membership values which range is from 0 to 1. It is having ability to reason and use approximate data to find solutions. Fuzzy logic controllers are knowledge-based controllers consisting of IF-THEN rules that can be formed using the expert knowledge[8][9].

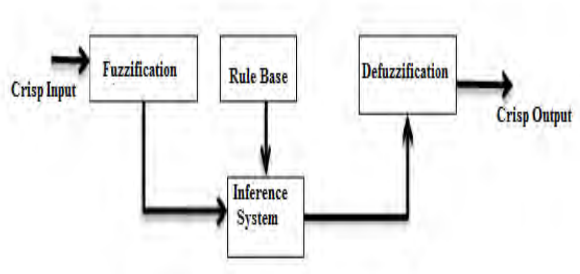

Fig. 2. Block diagram of fuzzy logic controller[1]

1) Rule base: If-Then rules are used to determine the conditional statements that comprises the fuzzy logic.
2) Fuzzy Inference System: It is the process of mapping from a given input to an output.
3) Fuzzification: To create a membership values for fuzzy variables.
4) Defuzzification: It converts the output of FIS into a crisp output.

For defuzzification process, the methods used are centroid, bisector, middle-smallest-largest of maximum. The most popular defuzzification method is the centroid, which calculates the output for aggregated fuzzy system using center of gravity.

IV. DESIGNING OF FUZZY LOGIC CONTROLLER

The fuzzy logic controller is mostly used for nonlinear systems and boiler drum level is also a highly nonlinear system. A system performance is observed using fuzzy logic mamdani and sugeno FIS in MATLAB. For this it is necessary to develope controller design in fuzzy toolbox with membership functions and rules. The controller which is designed is saved with .fis file by using mamdani and sugeno FIS. This file is then used on simulation platform for fuzzy logic controller. For PID controller the tuned parameters K_p, K_i, K_d are obtained using autotuning method.

A. FUZZY LOGIC USING MAMDANI AND SUGENO FIS

For Fuzzy logic controller, the error of drum level e and its rate of change of error is Δe as the input linguistic variables and the output is control value of water flow. The range for first input with membership function is from -1 to 1, for second input the range is from -0.1 to 0.1. And the range for control value of water flow is -32 to 32. The gaussian membership function is taken for all fuzzy sets of input and output. The corresponding fuzzy sets for both input and output are as follows,

$$E = \{NS, NM, NB, ZO, PS, PM, PB\}$$

For sugeno FIS, the two inputs are same with membership functions as that of mamdani FIS. There is only difference in output which is having linear values without membership functions which range is from -32 to 32. Fuzzy rules are same for both FIS. The defuzzification in mamdani FIS uses centroid method while sugeno FIS will use wtaver method to calculate the aggregate value of output.

B. FUZZY CONTROL RULES

The fuzzy controller will control the drum water level. The output is the water flow. When the amount of error is more and system is unstable, then error is removed by these rules. When the amount of error is small, then the system is more stable. And the supply of water flow is increased or decreased depending on the rate of change of error which is either positive or negative. For this the rules are designed in fuzzy toolbox as given in table I.

The proposed controller for boiler drum level system consists of fuzzy logic controller, boiler drum level system

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TABLE I. 49 RULES FOR BOILER DRUM LEVEL CONTROL

Δe / e	NS	NM	NB	ZO	PS	PM	PB
NS	NS	NM	NB	NS	ZO	PS	PM
NM	NM	NM	NB	NM	NS	ZO	PS
NB	NB	NB	NB	NM	NS	NS	ZO
ZO	NS	NM	NB	ZO	PS	PM	PB
PS	ZO	NS	NM	PS	PS	PM	PB
PM	PS	ZO	NS	PM	PM	PM	PB
PB	PS	PS	ZO	PM	PB	PB	PB

is shown in figure 3. The response of a system is observed using fuzzy control have a great control towards overshoot and settling time, rise time and minimizes the performance indices as shown in figure 4.

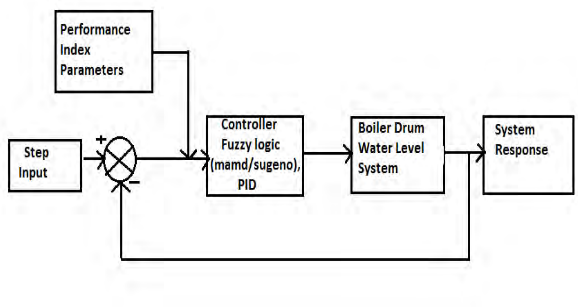

Fig. 3. Proposed controller for boiler drum water level system

V. DEVELOPEMENT OF GUI

For the development of GUI, first the simulation results are observed using fuzzy in mamdani and sugeno FIS and PID controller. The tuning parameters of PID controller are obtained by autotuning method.

GUI is generated in MATALB by writing a code in .m

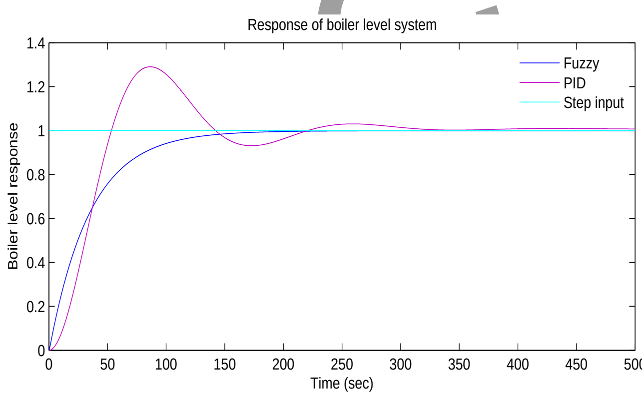

Fig. 4. Response of system using Fuzzy and PID controller

file. From GUI we can able to select the type of controller and type of process. GUI for boiler drum level system will shows the system response with time domain specifications like rise time, settling time minimum and maximum, peak overshoot and performance indices like IAE, ITAE, ISE, ITSE by using fuzzy logic controller in mamdani and sugeno FIS.

The comparison of performance parameters of a boiler drum level system is observed by using PID and FLC are

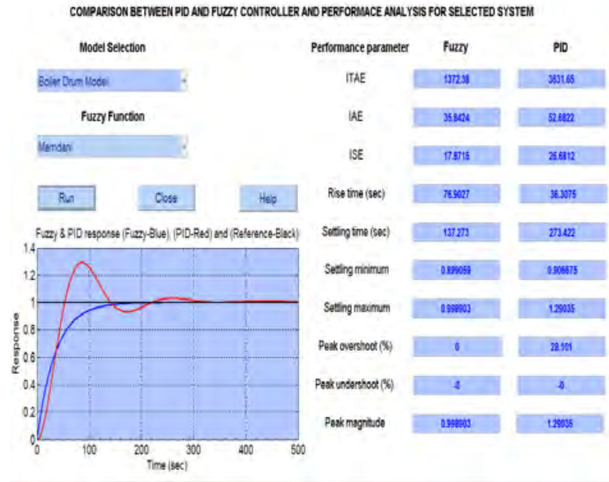

Fig. 5. GUI for boiler drum water level system

shown in observation table.

TABLE II. PERFORMANCE PARAMETERS OF BOILER DRUM WATER LEVEL CONTROL SYSTEM

Parameters	PID	Mamdani	Sugeno
ITAE	3631.65	1372.38	1372.38
IAE	52.6822	35.84	35.84
ISE	26.6812	17.8715	17.8715
ITSE	716.3	314.3	314.3
Rise time(sec)	36.3075	76.9027	76.9027
Settling time(sec)	273.4224	137.2733	137.2733
Peak overshoot(%)	28.101	0	0

VI. CONCLUSION

This paper presents the dynamic mathematical modelling for boiler drum level control and system performance is observed by using fuzzy logic mamdani and sugeno FIS, PID controller in GUI. From the results it is observed that the performance parameters of system using fuzzy logic will gives reduced overshoot, less settling time and rising time and errors are also minimum as compared to PID controller. The results of mamdani and sugeno FIS are same but sugeno FIS is more flexible than mamdani FIS. Also the time required for defuzzification process is more for mamadani FIS while sugeno FIS requires less time. The fuzzy logic control is much better than the PID control.

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