FUZZY APPLICATIONS IN A POWER STATION

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ABSTRACT

Power generation today is an increasingly demanding task, worldwide, because of emphasis on efficient ways of generation. A power station is a complicated multivariable controlled plant, which consists of boiler, turbine, generator, power network and loads. The power sector sustainability depends on innovative technology and practices in maintaining unit performance, operation, flexibility and availability . The demands being placed on Control & Instrumentation engineers include economic optimization, practical methods for adaptive and learning control, software tools that place state-of-art methods . As a result, Fuzzy techniques are explored which aim to exploit tolerance for imprecision, uncertainty, and partial truth to achieve robustness, tractability, and low cost. This paper proposes use of fuzzy techniques in two critical areas of Soot Blowing optimization and Drum Level Control.

Presently, in most of the Power stations the soot blowing is done based on a fixed time schedule. In many instances, certain boiler stages are blown unnecessarily, resulting in efficiency loss. Therefore an fuzzy based system is proposed which shall indicate individual section cleanliness to determine correct soot blowing scheme. Practical soot blowing optimization improves boiler performance, reduces NOx emissions and minimizes disturbances caused by soot blower activation. Due to the dynamic behaviour of power plant, controlling the Drum Level is critical. If the level becomes too low, the boiler can run dry resulting in mechanical damage of the drum and boiler tubes. If the level becomes too high, water can be carried over into the Steam Turbine which shall result in catastrophic damage. Therefore an fuzzy based system is proposed to replace the existing conventional controllers

KEYWORDS

Artificial intelligence, Expert Systems, Fuzzy Logic, Power generation, Soot Blowers, Drum Level

I. INTRODUCTION

The Government owned Power station in India that has been considered in this paper is a Fossil fired 500 MW Power Station. The overview of a 500 MW unit is shown in figure 1. The Soot blowing system consists of 88 Wall Blowers in a 500 MW Coal based power plant in India. The paper presents a Fuzzy rule-based system to estimate the cleanliness factor of the boiler. The cleanliness factor is calculated based on certain identified variables. The Drum level control strategies are reviewed for a 500 MW Boiler using fuzzy logic. In the first strategy the PID controller gains are varied based on fuzzy logic rules. Fuzzy rules are utilized on-line to determine the controller parameters based on tracking error and its first time derivative. In the second strategy the Drum level setpoint is varied based on fuzzy logic rules. Simulation and experimental results of the proposed schemes show good performances of fuzzy based strategies in terms of dynamic and steady state characteristics of all loops. Simulations are performed using MATLAB/SIMULINK

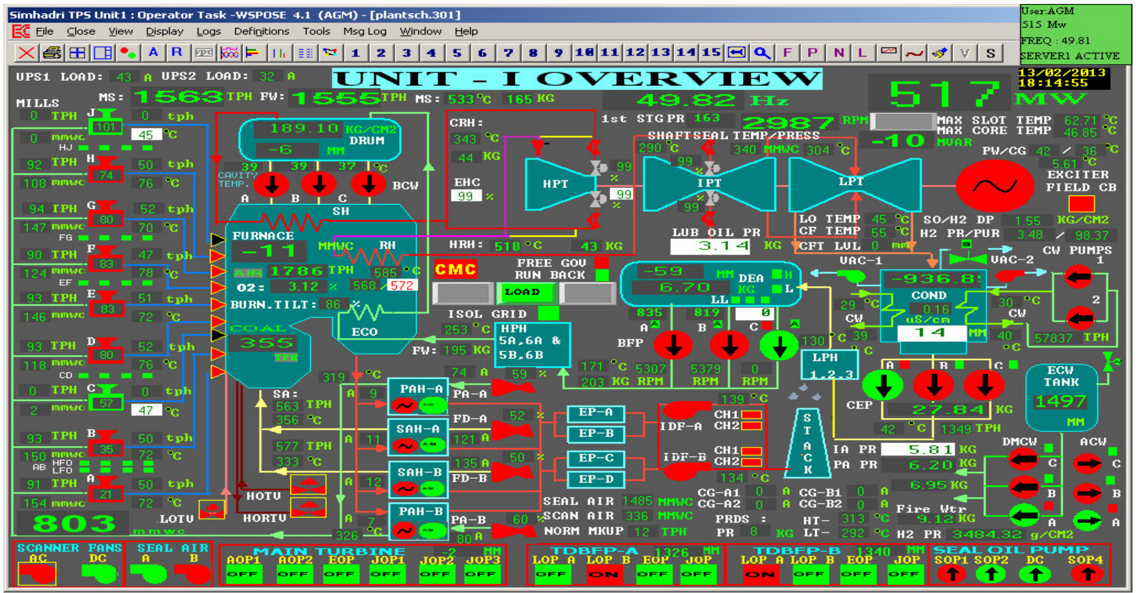


Fig. 1 Overview of a 500 MW unit

II. SOOT BLOWING SYSTEM

The soot blowing is done based on a fixed time schedule in many Power stations [1]. This paper propose a Fuzzy logic system designed to advise on Where and When to blow the soot depending on a single attribute called Cleanliness Factor. In contrast to the standard approach regarding soot blowing, cost optimized soot blowing determines continuously, when a specific soot blower group (level) shall be operated. Thus the soot blowing strategy inevitably changes from cleaning of the entire boiler to cleaning of individual heating surfaces.

Furnace and convective pass slagging and fouling have a negative effect on boiler performance, emissions, and unit availability. Furnace Slagging reduces heat transfer to waterwalls and increases amount of heat available to convection pass leading to higher FEGT(Furnace Exit Gas Temperature), higher steam temperature, higher desuperheating spray flows, reduced performance and higher NOx emission.Convective Pass Slagging and Fouling reduces heat transfer in convection pass leading to lower steam temperature, reduced performance ,lower desuperheating spray flows and increased flue gas temperature at boiler exit. [1].However regular sootblowing can result in over-cleaning of furnace walls leading to low steam temperatures , increased moisture levels and erosion damage in last stages of LP turbine, lower turbine and unit power output (due to reduced reheat steam temperature) . Sootblowing of boiler convective pass increases heat transfer in that region resulting in increases steam temperatures and desuperheating sprays, and reduces flue gas temperature at boiler exit. Hence for best performance it is important to maintain an optimal balance between furnace and convective pass heat transfer. The resultant requirement is the SootBlowing Optimization [2].

The general layout of Soot blowers in a 500 MW is shown in figure 2.

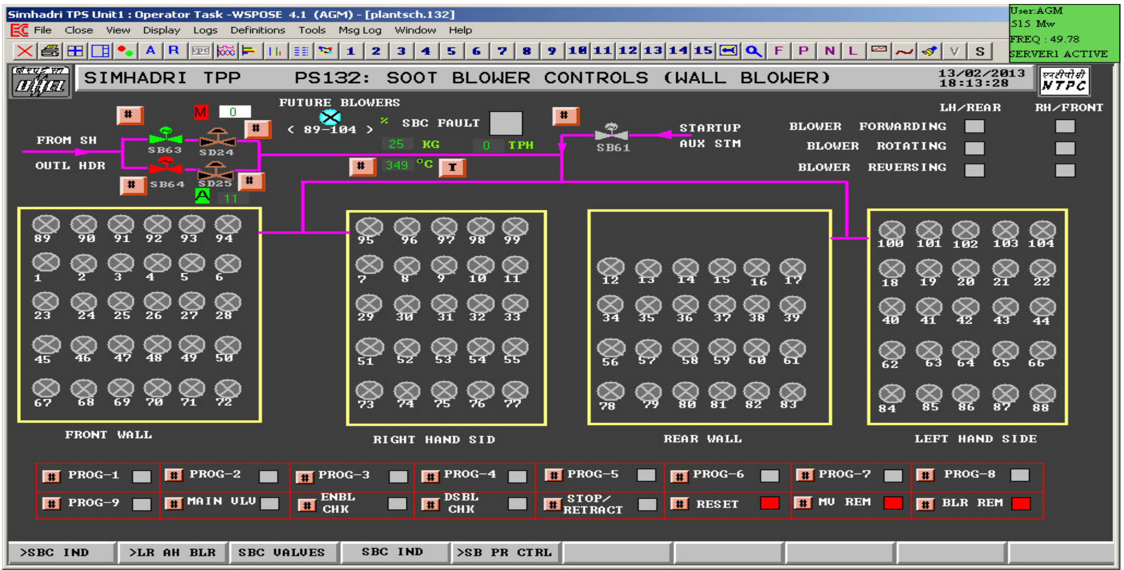


Fig. 2 General Layout of Soot Blowing system in a 500 MW unit

A fixed sootblowing schedule programmed into the sootblower control system indicated that sequential activation of all 88 wall blowers produced large cyclic variations in main steam temperature. The main steam temperature rose as the convection pass was cleaned and fell as slag was scoured from the furnace water walls. Such cycling of main steam temperatures is not desirable because it stresses both the boiler and the steam turbine.

The boiler section fouling status can be quantified by the section cleanliness factor (CF)[3]. By definition, cleanliness factor is the ratio of actual to design heat transfer rate.

III. FUZZY LOGIC DESIGN

The fuzzy logic system consists of three different types of entities. -Fuzzy sets, fuzzy variables and fuzzy rules. The membership of a fuzzy variable in a fuzzy set is determined by a function that produces values within the interval [0,1]. These functions are called membership functions. The fuzzy rules determine the link between the antecedent and consequent fuzzy variables and are often defined using natural language linguistic terms. A fuzzy if-then rule associates a condition about linguistic variables to a conclusion. The degree the input data matches the condition of a rule is combined with the consequent of the rule to form a conclusion inferred by the fuzzy rule. A fuzzy logic controller consist of three section namely fuzzifier, rule base and defuzzifier as shown in fig.3. The fuzzifier transforms the numeric/crisp value into fuzzy sets; therefore this operation is called fuzzification. The main component of the fuzzy logic controller is the inference engine, which performs all logic manipulations in a fuzzy logic controller. The rule base consists of membership functions and control rules. Lastly, the results of the inference process is an output represented by a fuzzy set, however, the output of the fuzzy logic controller should be a numeric/crisp value. Therefore, fuzzy set is transformed into a numeric value by using the defuzzifier. This operation is called defuzzification[4]. For the proposed study, Mamdani fuzzy inference engine is selected and the centroid method is used in defuzzification process.[4,5,6]

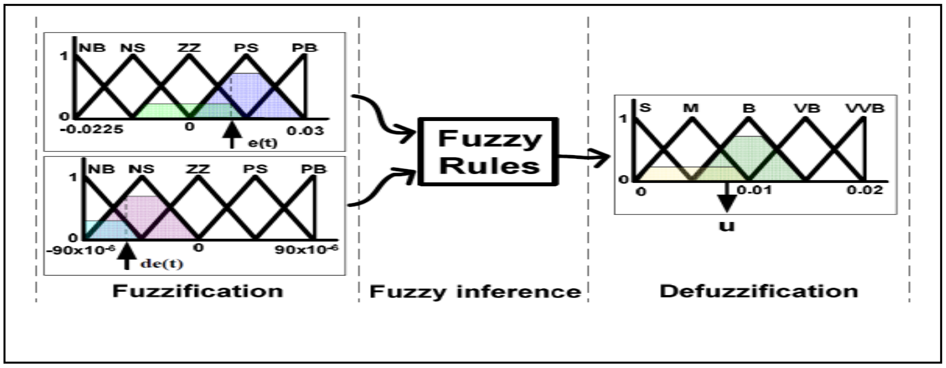


Fig. 3 Fuzzy Logic system

A method of estimating the cleanliness factor in furnace is estimated by using fuzzy logic. The following input variables are identified for fuzzification[3].

a) SH metal temperature
b) Total spray flow
c) Burner Tilt
d) Mill Combination
e) Load
f) Elapsed Time since last soot blowing

The fuzzy sets defining for the above variables are as follows:
LOAD (MW) : {Low, Average, High}
TEMP oC : {Low, Normal, High}
SPRAY(TPH): {Low, Normal, High}
BURNER TILT (deg.) : {Down, Normal, UP}
MILLCOMBINATION : {Lower, Other, UP}
TIME IN HR : { Short, Average, Long.}
The cleanliness factor ,chosen as the objective function co (Command Output), is given by: CF (%) - {Dirty, Clean}
The Linguistic variables and their ranges are given in Table –1

Table –1

Linguistic Value	Notation	Ranges
Gaussian MF	LOAD	
Low	L	[450,480]
Average	A	[470,500]
High	H	[490,520]
Bell MF	LTSH Temperature	
Low	L	[520,530]
Normal	N	[530.540]
High	H	[540,550]

Gaussian MF	Spray	
Low	L	[20,40]
Normal	N	[25,55]
High	H	[40,60]
Gaussian MF	Burner Tilt	
Down	D	[-30,0]
Normal	N	[-20,20]
Up	U	[0,30]
Gaussian MF	Mill combination	
Lower	L	[0,.5]
Other	O	[.1, .9]
Upper	U	[.5, 1]
Bell MF	Time since last SB	
Short	S	[0.4]
Average	A	[2,18]
Long	L	[10,24]
Bell MF	Cleanliness Factor	
Dirty	D	[0,82]
Clean	C	[70,100]

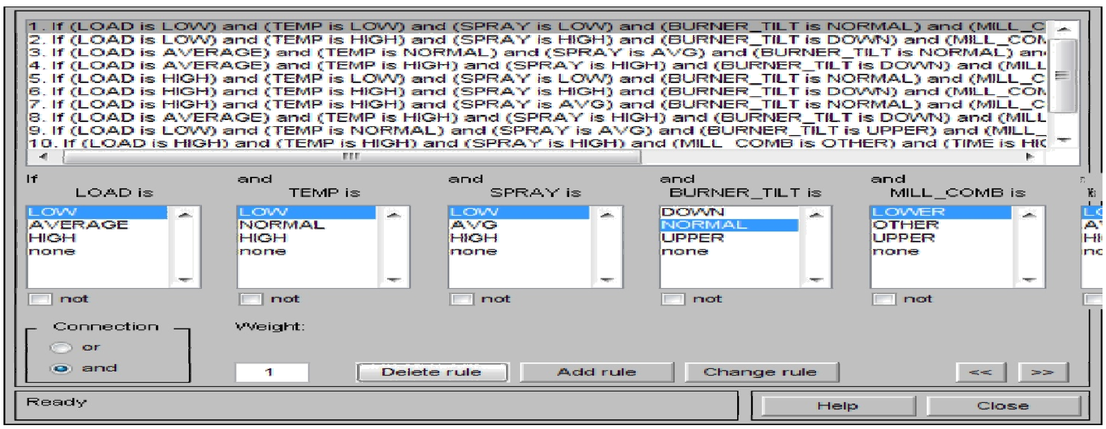
Considering most of the possible scenarios in the Boiler operating conditions twelve rules are framed for the Fuzzy system. Table-2 and Table-3

Table 2

Rule	Load	Temp	Spray	Tilt	Mill Com	`Time	Out put	Commd
1	Lo	Lo	Lo	Nor	Lower	Lo	Clean	0
2	Lo	Hi	Hi	Down	Upper	Hi	Dirty	1
3	Avg	Nor	Nor	nor	other	Avg	Clean	0
4	Avg	Hi	Hi	Down	other	Hi	Dirty	1
5	Hi	Lo	Lo	Nor	Upper	Avg	Clean	0
6	Hi	Hi	Hi	Down	Other	Hi	Dirty	1
7	Hi	Hi	Nor	No	Upper	Avg	Clean	0

8	Avg	Hi	Hi	Down	Lower	Avg	Dirty	1
9	Lo	Nor	Nor	Up	Upper	Avg	Clean	0
10	Hi	Hi	Hi	X	Other	Hi	Dirty	1
11	Hi	Hi	Hi	Down	Lower	Hi	Dirty	1
12	X	Hi	Hi	Down	X	X	Dirty	1

Table-3



The Configuration of Fuzzy logic using MATLAB is shown in Figure 4. The configuration has 6 input variables and 1 output variable.

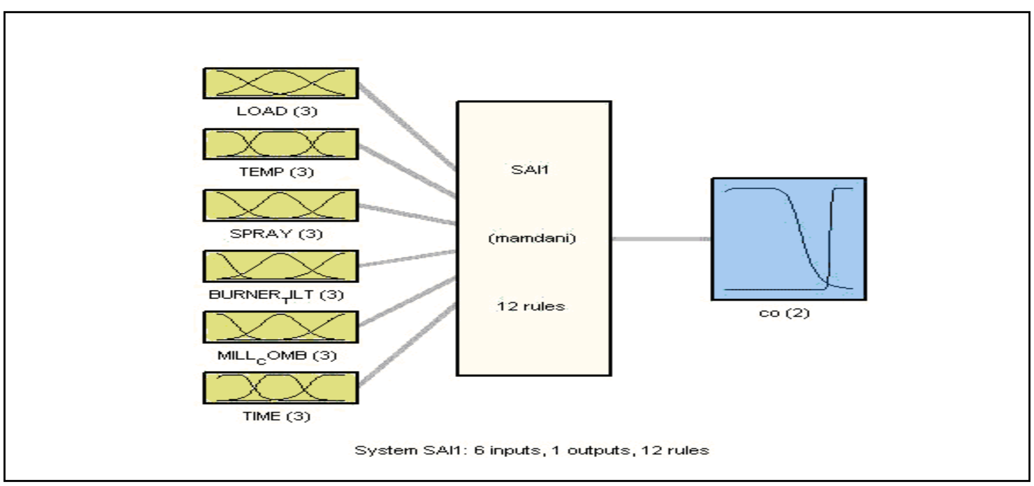


Fig. 4 Configuration of Soot blowing System in Fuzzy Logic

IV. FUZZY INPUT / OUTPUT MEMBERSHIP FUNCTIONS

The membership function for all the six input variables and one output variable is discussed. The fuzzy sets describing LOAD, TEMP, SPRAY, TILT, MILL COMB, TIME and Output Cleanliness Factor (CF) are illustrated in figures 5 to 7.

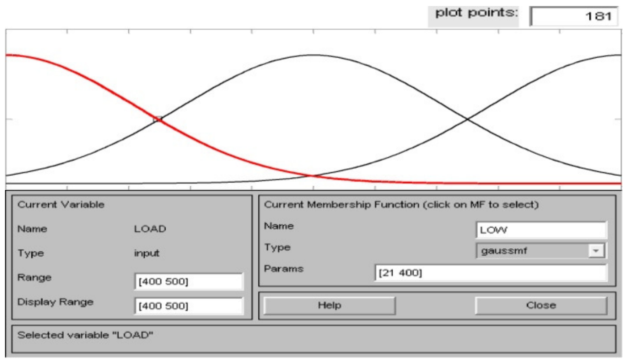


Fig.5 LOAD MF

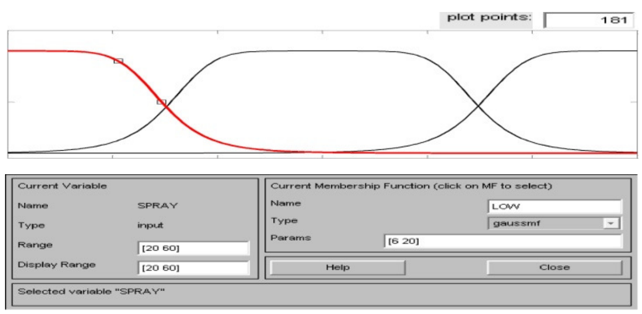


Fig. 6 SPRAY MF

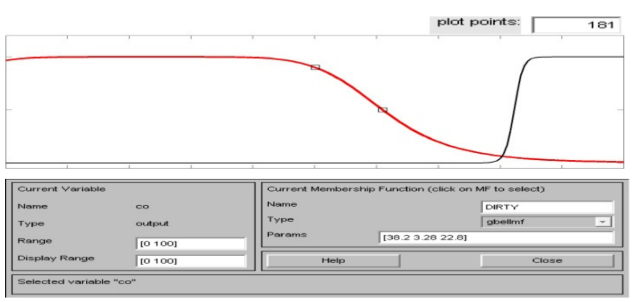


Fig. 7 OUTPUT (CF) MF

The surface view of various input combinations and Command Output (CF) is shown in Figure 8

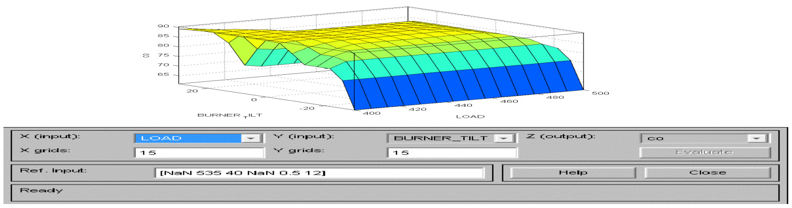


Fig. 8 Surface view of Load, Burner tilt and CO

Results

A MATLAB based program is developed to compute the values of the output for given different input values. This program utilizes 'Fuzzy Inference System'. It calculates the crisp values of the outputs for given inputs. The Fuzzy based soot blowing strategy satisfies the optimization objectives of Lowest operating cost, maximise power generation, Minimises maintenance cost and avoids unmanageable soot build up. The sample results of the MATLAB with six inputs as shown in Table - 4, estimates the Cleanliness Factor from the Fuzzy Soot Blowing Model

Results:

Enter LOAD:(MW):490
Enter SH METAL TEMP: (C): 540
Enter TOTAL SPRAY: (T/H): 20
Enter BURNER TI LT :(degree): -15
Enter MILL COMBINATION: 0.5
Enter TIME SINCE lAST S/B: 15
CLEANLINESS FACTOR OF THE FURNACE is 89.335727

Table-4 Data For estimating CF

Load MW	**SH temp**	**Spray**	**Burner tilt**	**Mill com**	**Time Hr**	**CF %**
490	**540**	**20**	**-15**	**0.5**	**15**	**89.3**
493	**545**	**25**	**-15**	**0**	**24**	**87.3**
492	**529**	**35**	**-10**	**0**	**24**	**51.1**
494	**545**	**30**	**10**	**1**	**22**	**89.7**
497	**546**	**30**	**0**	**1**	**20**	**91**
499	**525**	**50**	**-15**	**.6**	**25**	**48.2**
489	**530**	**20**	**30**	**0**	**22**	**69.8**

IV. DRUM LEVEL CONTROL

The boiler drum is where water and steam are separated. The general layout of a 500 MW Drum level control loop is shown in Figure 9.

The 3 element drum level control is shown in figure 10 . The elements correspond to the three variables that are used as indices of control variables: drum liquid level, feed-water flow, and steam flow. The drum level controller maintains a constant drum level using the flow demand as a set point and uses the drum level process variable as a feedback signal.[5]

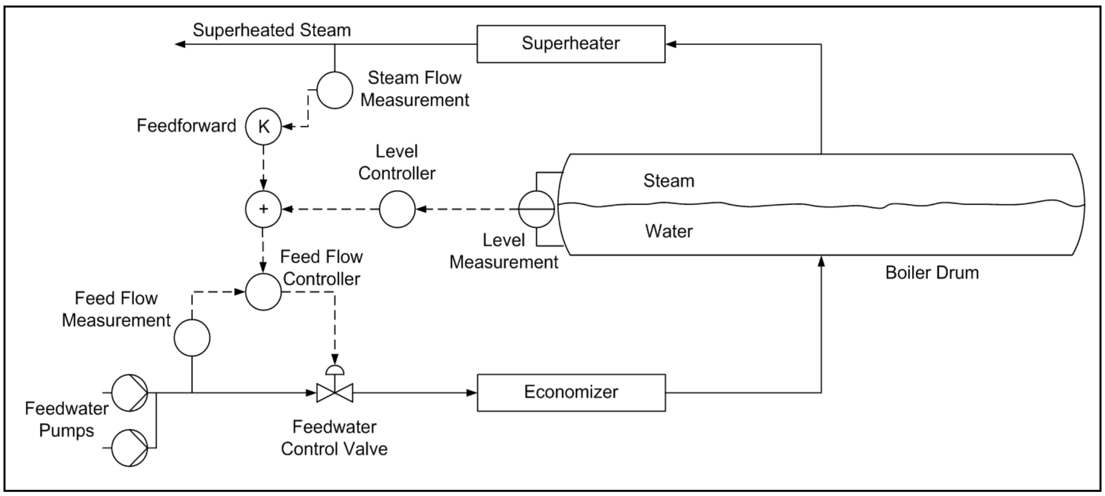


Fig. 9 500 MW Drum Level control loop

The Drum level is derived from the following equation:

$h = DP + H (\gamma r - \gamma s) + (\gamma w - \gamma s)$

where:

h = True drum level – Inches

DP = Measured DP head – Inches

H = Distance between taps – Inches

γs = Steam Specific Gravity (S.G.)

γr = Reference leg (S.G.)

γw = Drum Water (S.G.)

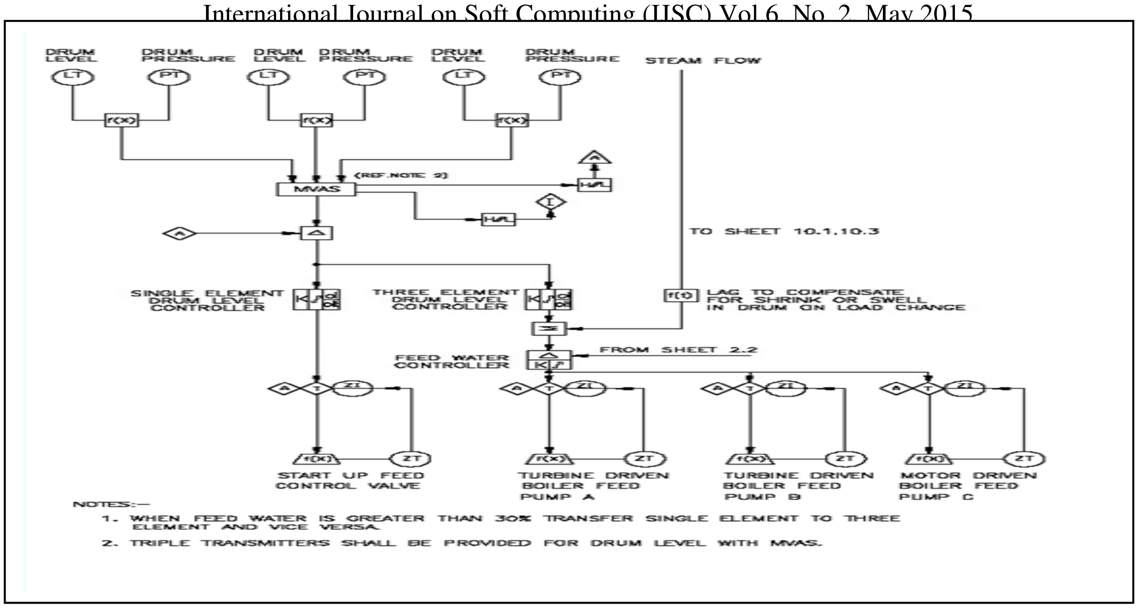


Fig. 10 3-Element Drum Level control loop

PID controller constants obtained during performance guarantee tests done by DCS (Distributed Control System) supplier normally hold good for all times. However due to aging of the plant or due to special operating situations (FGMO- Free governing Mode operation, high fluctuations in coal quality , fuel switching, different load conditions etc) there is a need for changing the PID parameters. Hence a new method is to be devised to change the PID controller parameters.The fuzzy logic controller (FLC) proposed here is intended to show the flexibility, adequacy and reliability of the boiler operation while using the fuzzy logic control action.

Fuzzy gain scheduling is considered to be the most promising alternative combining fuzzy logic with conventional controllers. A rule based scheme for gain scheduling of PID controllers for drum level control is designed in this paper. The new scheme utilizes fuzzy rules and reasoning to determine the controller parameters and the PID controller generates the control signal.The Fuzzy Gain Scheduler proposed in this paper can also be applied to any control loop in the plant, which consists of a PID controller. Fuzzy PID tuning is no longer a pure knowledge or expert based process and thus has potential to be more convenient to implement. The approach taken here is to exploit fuzzy rules and reasoning to generate controller parameters. For the proposed study, Mamdani fuzzy inference engine is selected and the centroid method is used in defuzzification process.[5,6,7]

The PID controller parameters (K p, Ki, Kd) are determined based on the current error e (t) and its derivate Δ e (t) .Proportional controller has the effect of increasing the loop gain to make the system less sensitive to load disturbances, the integral error is used principally to eliminate steady state errors and the derivative action helps to improve closed loop stability. The parameters Kp, Ki and Kd are thus choosen to meet prescribed performance criteria , classically specified in terms of rise and settling times, overshoot and steady state error , following a step change in the demand signal.

The fuzzy adapter adjusts the PID parameters to operating conditions, in this case based on the error and its first difference, which characterizes its first time derivative, during process control. The structure of the fuzzy gain scheduler is illustrated in figure. 11 [8,9]

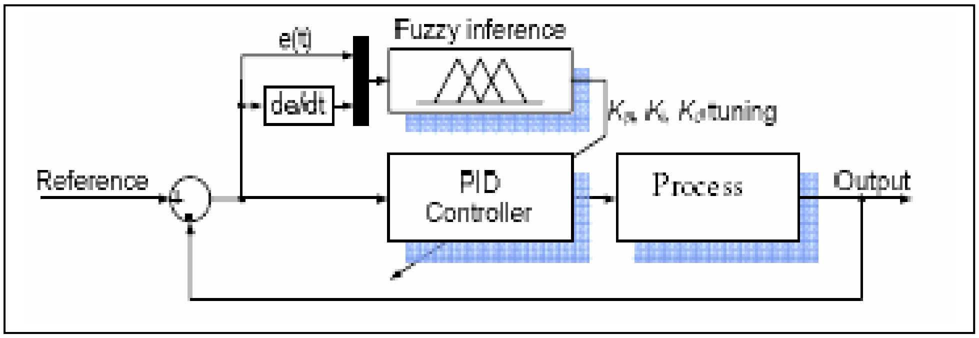


Fig. 11 Fuzzy Gain Scheduler Structure

The Fuzzy Gain Controller of Drum level control loop has 2 inputs (error e and derivative of error de) and three outputs Kp , Ki and Kd. Domain of e is (-9,9), de is(-6,6) and the fuzzy set of e and de are NB(Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM(Positive Medium), PB (Positive Big).

Domain of Kp is {0, 200}, Ki is {0, 8} and Kd is {0, 40} and the fuzzy set of Kp, Ki,Kd is { NB (Negative Big) NM (negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM(Positive medium), PB (Positive Big)} The fuzzy sets are all triangular MF.

When e is large , in order to the system to enable the system to fast track, a large Kp and a small Kd is selected. In order to prevent the system overshoot to be too large, the integral term is limited. When e is in the medium value , in order to make the system have a smaller overshoot, Kp is made smaller. In this case Kd impacts on the system response than the other factors . When e is small, in order to make the system has good steady-state performance, Kp and Ki are made larger. Meanwhile , in order to avoid the system oscillating near the set value , the selection of Kd is critical. Taking into account the interaction between the three parameters and the analysis, the control rules are established for Kp, Ki, and Kd as shown in Table 5 to 8

Table-5 Fuzzy tuning rules for Kp Change in error e

Change in derivative error de	NB	NM	NS	ZO	PS	PM	PB
NB	PS	ZO	NS	NB	NS	ZO	PS
NM	PB	PS	ZO	NS	ZO	PS	PB
NS	PB	PB	PS	ZO	PS	PB	PB
ZO	PB	PB	PB	PS	PB	PB	PB
PS	PB	PB	PS	ZO	PS	PB	PB
PM	PB	PS	ZO	NS	ZO	PS	PB
PB	PS	ZO	NS	NB	NS	ZO	PS

Table-6 Fuzzy tuning rules for Ki

Change in error e

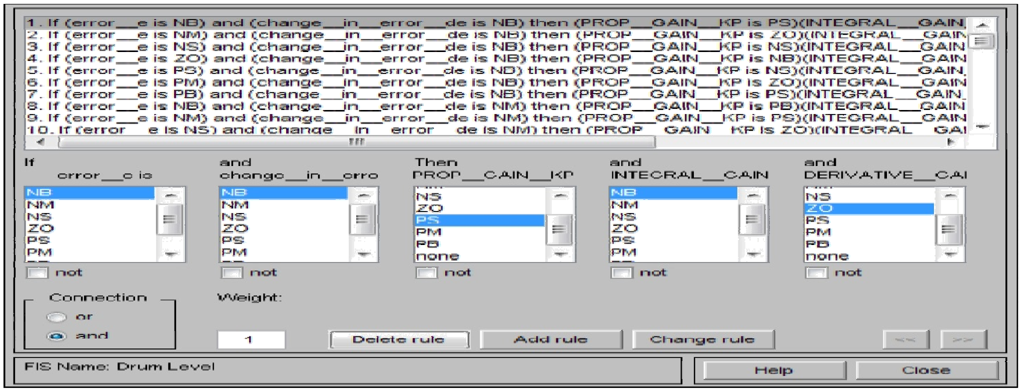
Change in derivative error de	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NS	ZO	NS	NB	NB
NM	NB	NS	ZO	PS	ZO	NS	NB
NS	NS	ZO	PS	PB	PS	ZO	NS
ZO	NS	PS	PB	PB	PB	PS	NS
PS	NS	ZO	PS	PB	PS	ZO	NS
PM	NB	NS	ZO	PS	ZO	NS	NB
PB	NB	NB	NS	ZO	NS	NB	NB

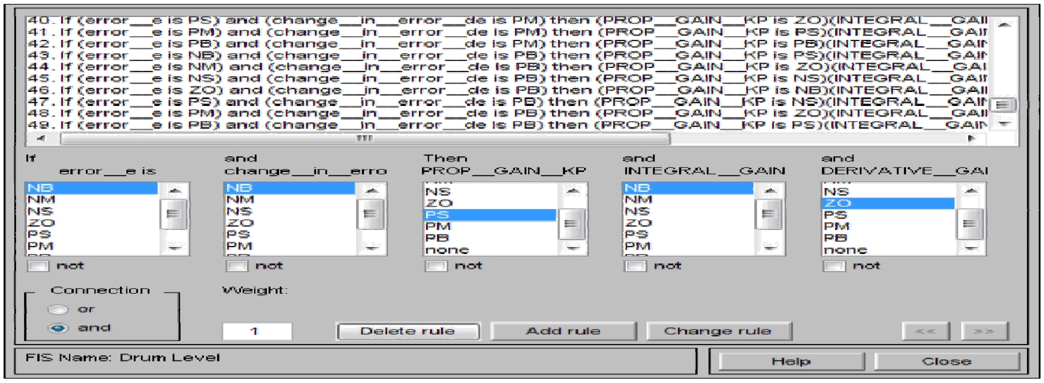
Table-7 Fuzzy tuning rules for Kd

Change in error e

Change in de	NB	NM	NS	ZO	PS	PM	PB
NL	ZO	PS	PB	PB	PB	PS	ZO
NM	NS	ZO	PS	PB	PS	ZO	NS
NS	NB	NS	ZO	PS	ZO	NS	NB
ZO	NB	NS	ZO	PS	ZO	NS	NB
PS	NB	NS	ZO	PS	ZO	NS	NB
PM	NS	ZO	PS	PB	PS	ZO	NS
PL	ZO	PS	PB	PB	PB	PS	ZO

Table-8 49 Fuzzy rules





The configuration of the Fuzzy PID control block in MATLAB is shown in Figure 12.

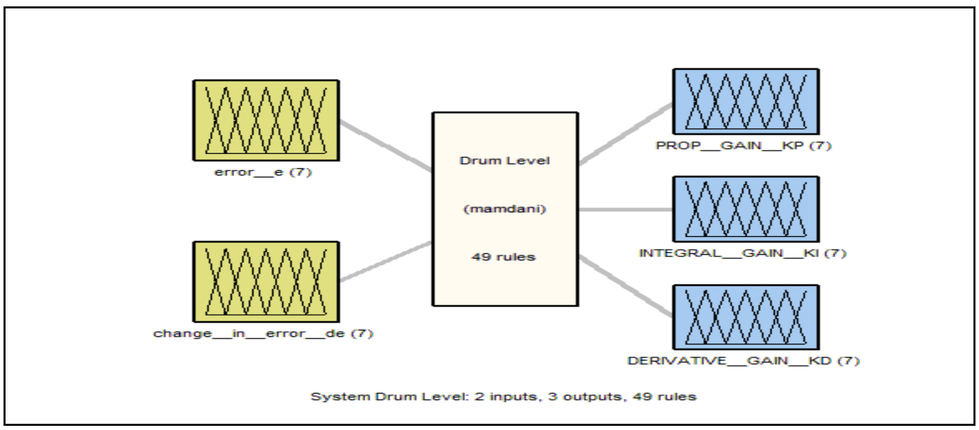


Fig 12. Fuzzy PID configuration

The Simulink Model for the three element Drum Level Control for Conventional PID Control is shown in Figure 13.

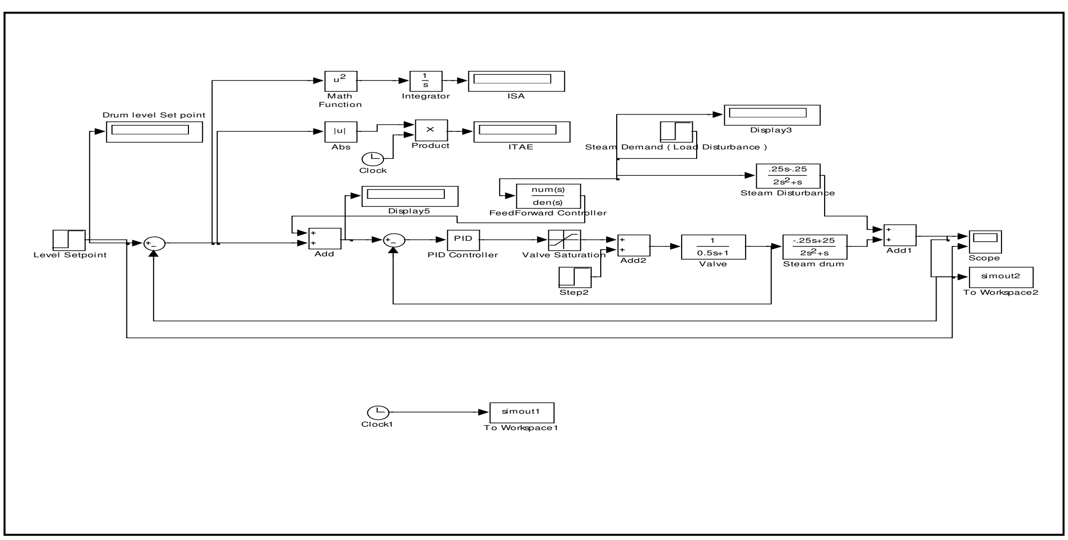


Fig. 13 Simulink Model for the three element Drum Level Control for Conventional PID Control

The Simulink Model for the three element Drum Level Control using Fuzzy Gain Scheduling is shown in Figure 14

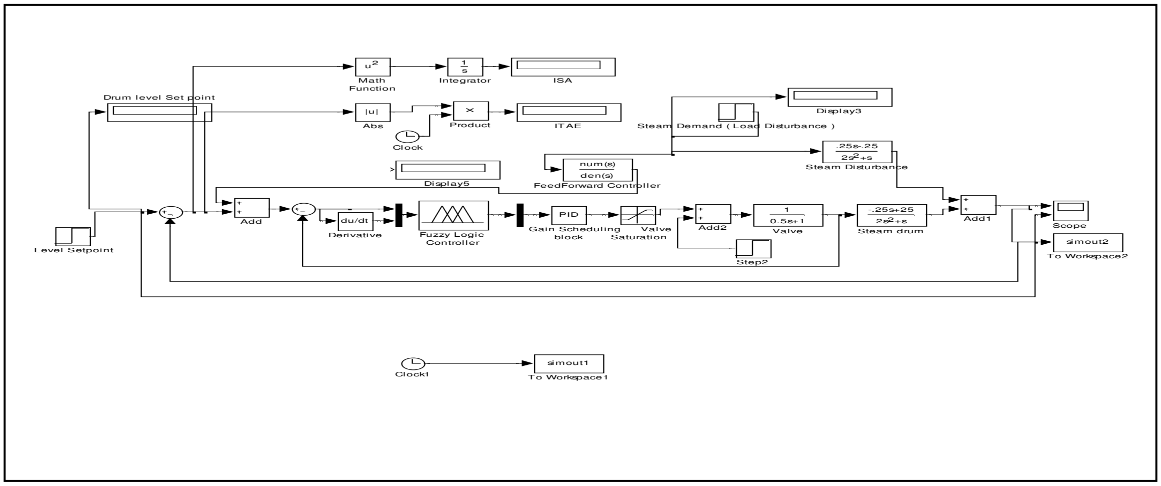


Fig. 14 Simulink Model for the three element Drum Level Control using Fuzzy Gain Scheduler

V. CONCLUSION

The purpose of this paper is to demonstrate the fuzzy techniques in a Power Station. The intelligent soot blowing system proactively modifies the soot blowing activities in response to real-time events or conditions within the boiler. The intent is to intelligently blow soot while satisfying multiple and specific user defined objectives using on-line, automated techniques. This application provides an asynchronous, event-driven technology that is adaptable to changing boiler conditions.This shall help in optimized soot blowing operation in a Power Plant. This application can further be implemented for all domains in the process plant. This will ensure the conversion of human expertise to knowledge base wherein the linguistic descriptions are translated into numeric data that yield qualitative results. The application of fuzzy logic to design the FGS controller for Drum Level control yields a practical solution that makes use of operation staff's experience and allows independent adjustment of controller parameters to control response. Results of simulation experiments demonstrate that the FGS algorithm may improve the performance of Drum Level control loop well beyond that obtained in conventional PID algorithm. Hence, the FGS proposed approach makes it possible to easily build high-performance tailor-made controllers for any specific control loop in the Power Plant thereby optimizing power plant efficiency and cost.

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