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# Boiler Cleanliness Factor Control Using Fuzzy Logic

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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 method. 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 technique in critical areas of Soot Blowing optimization. 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 a 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. Therefore an fuzzy based system is proposed to replace the existing conventional controllers*

## I. INTRODUCTION

The Private owned Power station in India that has been considered in this paper is a Coal fired 660 MW Power Station. The overview of a 660 MW unit is shown in figure 1. The Soot blowing system consists of 104 Wall Blowers in a 660 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. 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.

## II. SOOT BLOWING SYSTEM

The soot blowing is done based on a fixed time schedule in many Power stations. 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 water walls 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. 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.



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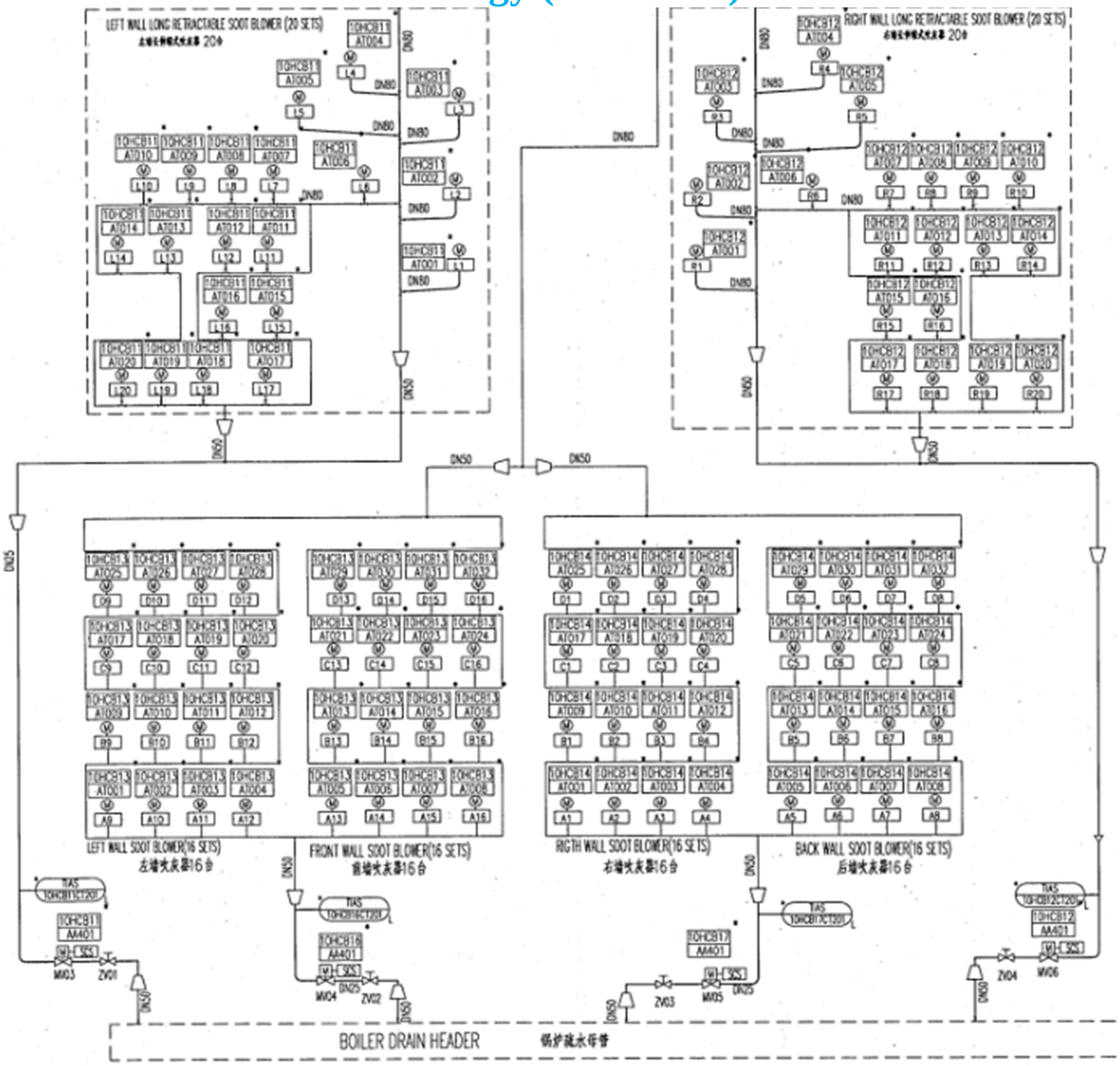


Fig.1 General Layout of Soot Blowing system in a 660 MW unit

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). 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 sections 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


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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. For the proposed study fuzzy inference engine is selected and the centroid method is used in defuzzification process.

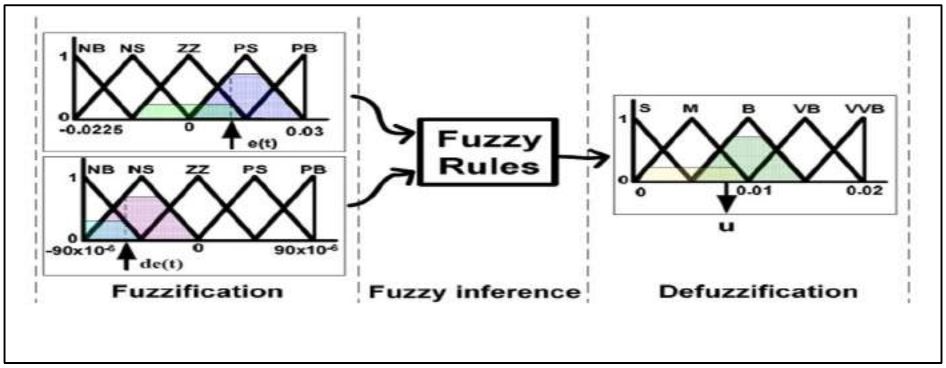


Fig. 2 Fuzzy Logic system

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

*A.* Load
*B.* SH metal temperature
*C.* Total spray flow
*D.* Burner Tilt
*E.* Mill Combination
*F.* Time since last soot blowing

The fuzzy sets defining for the above variables are as follows: LOAD (MW): {Low, Normal, High}
TEMP (C) : {Low, Normal, High} SPRAY( TPH): {Low, Normal, High}
BURNER TILT (deg.): {Down, Normal, UP} MILL COMBINATION: {Lower, Level, UP}
TIME SINCE LAST SB (hr.): {Short, Average, Long.}
The cleanliness factor, chosen as the objective function CF is given by: CF (%) - {Dirty, Clean}
The Linguistic variables and their ranges are given in Table –1

| Linguistic Value | Notation | Ranges |
|---|---|---|
| Gaussian MF | LOAD | |
| Low | L | [610,640] |
| Normal | N | [630,660] |
| High | H | [650,680] |
| Bell MF | SH Temperature | |
| Low | L | [520,530] |
| Normal | N | [530.540] |
| High | H | [540,550] |
| Gaussian MF | Spray Flow | |
| Low | L | [20,40] |
| Normal | N | [25,55] |
| High | H | [40,60] |
| Gaussian MF | Burner Tilt | |

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| | | |
|---|---|---|
| Down | D | [-30,0] |
| Normal | N | [-20,20] |
| Up | U | [0,30] |
| Gaussian MF | Mill combination | |
| Lower | Low | [0,.5] |
| Level | Lev | [.1, .9] |
| Upper | U | [.5, 1] |
| Bell MF | Time since last SB | |
| Short | S | [0,4] |
| Average | A | [3,21] |
| Long | L | [10,24] |
| Bell MF | Cleanliness Factor | |
| Dirty | D | [0,80] |
| Clean | C | [70,100] |

Table–1

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

| Rule | Load | Temp | Spray | Tilt | Mill Com | `Time | Output (CF) |
|---|---|---|---|---|---|---|---|
| 1 | Lo | Lo | Lo | Nor | Lower | Lo | Clean |
| 2 | Lo | Hi | Hi | Down | Upper | Hi | Dirty |
| 3 | Avg | Nor | Nor | Nor | Level | Avg | Clean |
| 4 | Avg | Hi | Hi | Down | Level | Hi | Dirty |
| 5 | Hi | Lo | Lo | Nor | Upper | Avg | Clean |
| 6 | Hi | Hi | Hi | Down | Level | Hi | Dirty |
| 7 | Hi | Hi | Nor | Nor | Upper | Avg | Clean |
| 8 | Avg | Hi | Hi | Down | Lower | Avg | Dirty |
| 9 | Lo | Nor | Nor | Up | Upper | Avg | Clean |
| 10 | Hi | Hi | Hi | X | Level | Hi | Dirty |
| 11 | Hi | Hi | Hi | Down | Lower | Hi | Dirty |
| 12 | X | Hi | Hi | Down | X | X | Dirty |

Table-2


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The Configuration of Fuzzy logic using MATLAB is shown in Figure 3 & 4. The configuration has 6 input variables and 1 output variable.

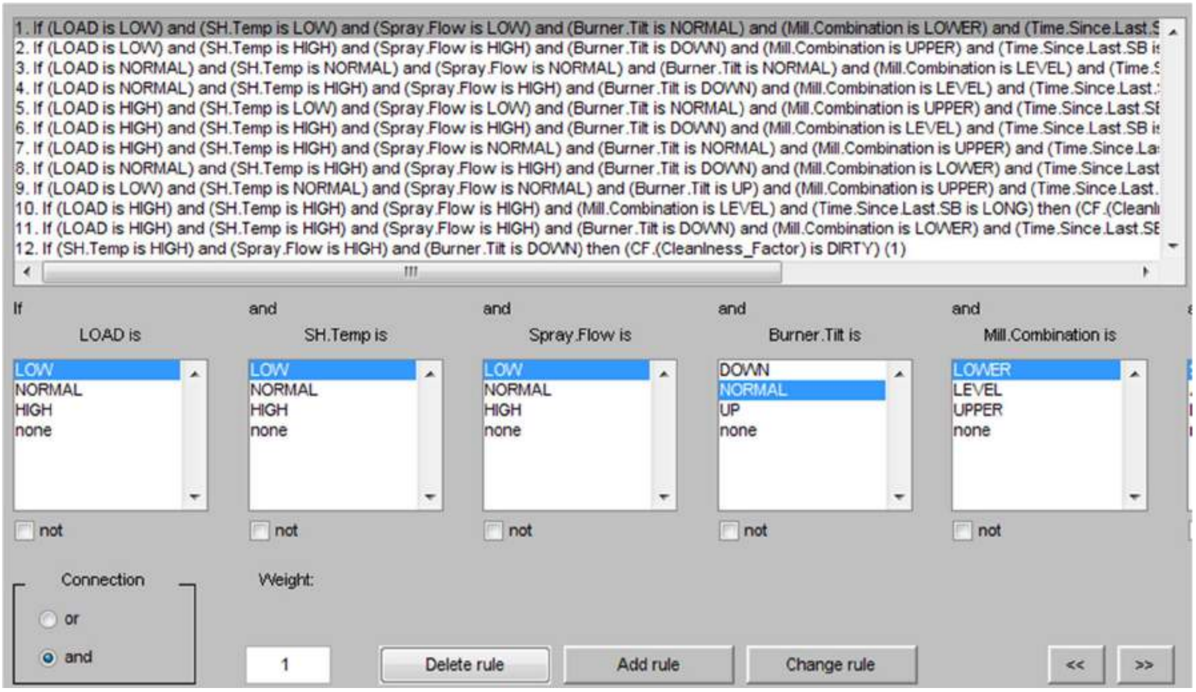


Fig.3 General Layout of Soot Blowing system in a 660 MW unit

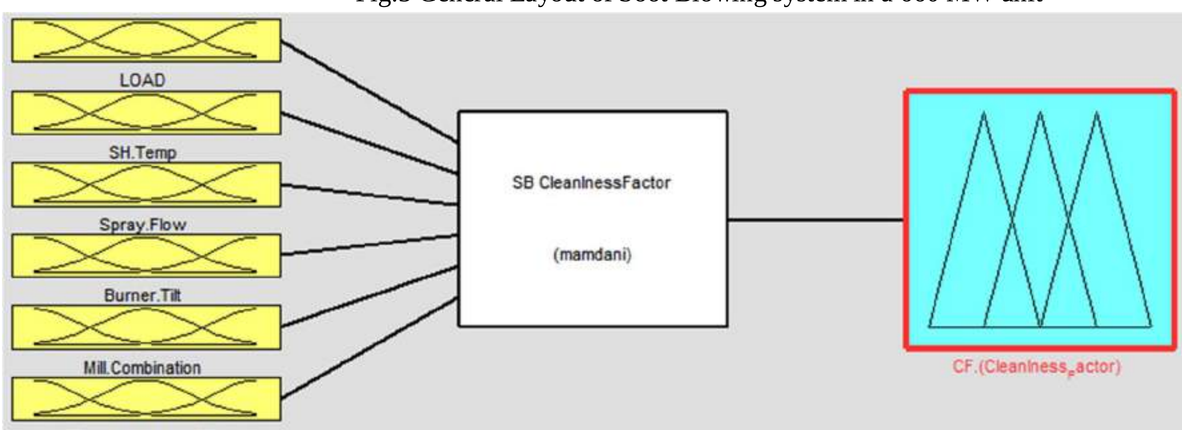


Fig. 4 Configuration of Soot blowing System in Fuzzy Log

## 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 12.

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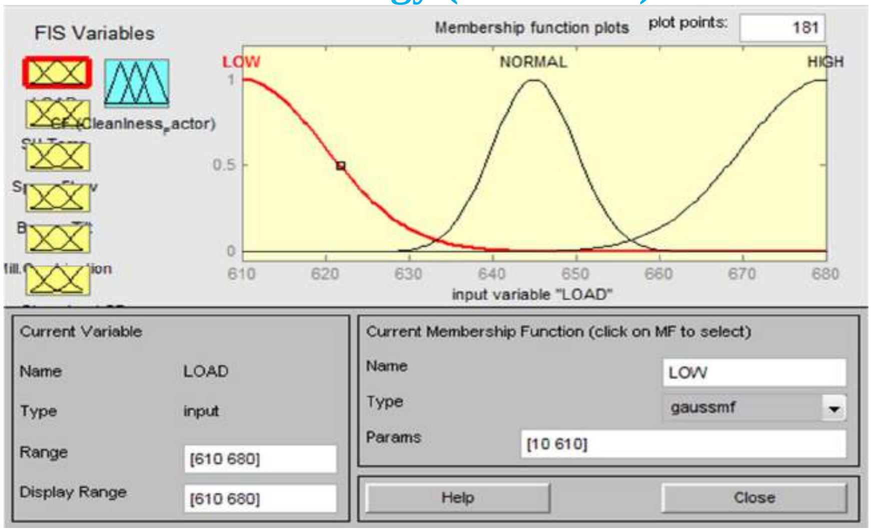


Fig.5 LOAD

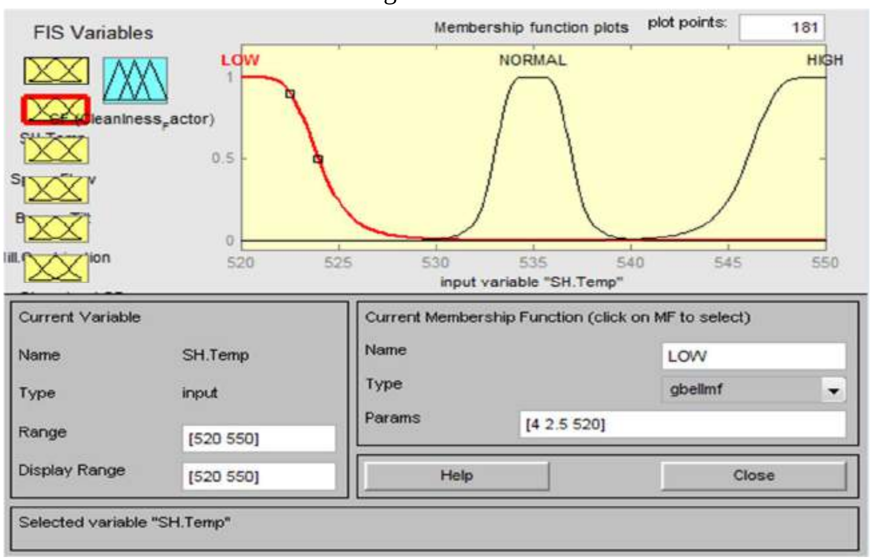


Fig. 6 SH Temp.

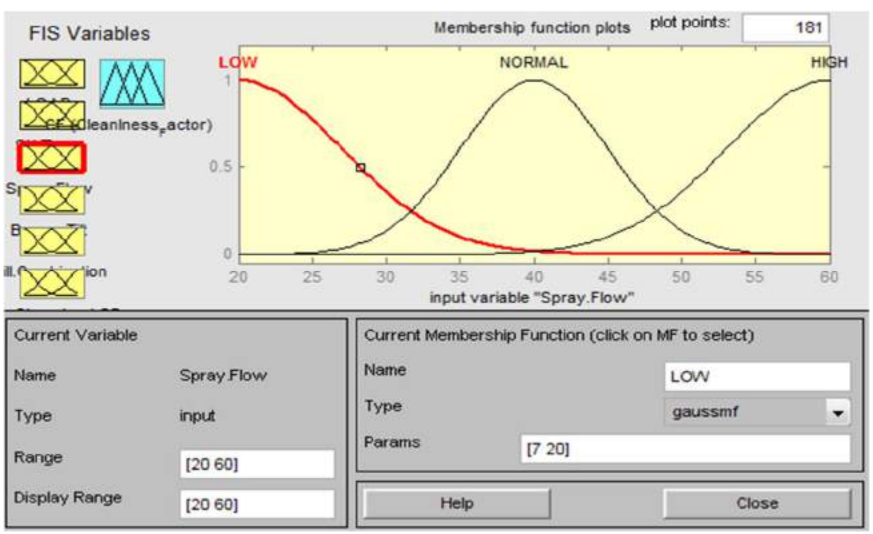


Fig. 7 Spray Flow

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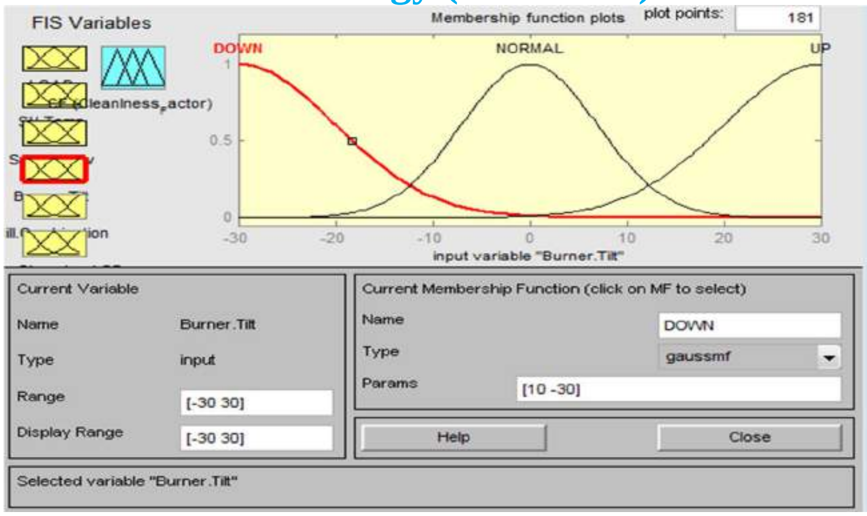


Fig. 8 Burner Tilt

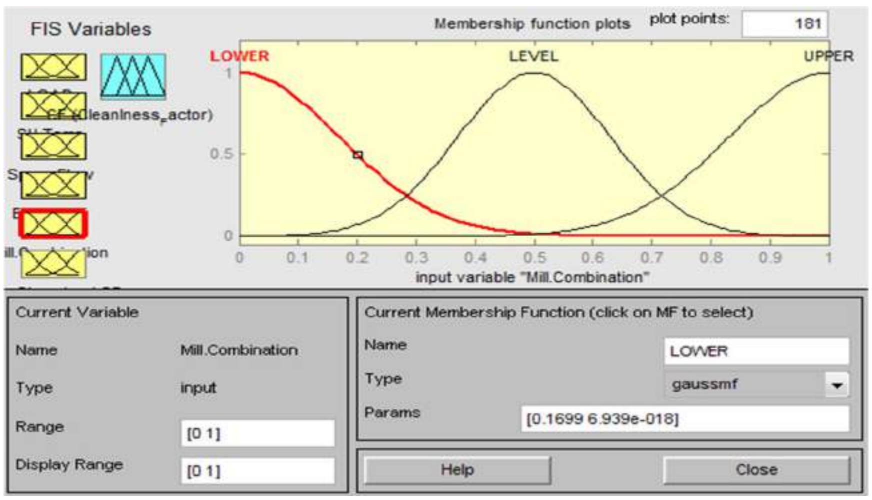


Fig. 9 Mill Combination

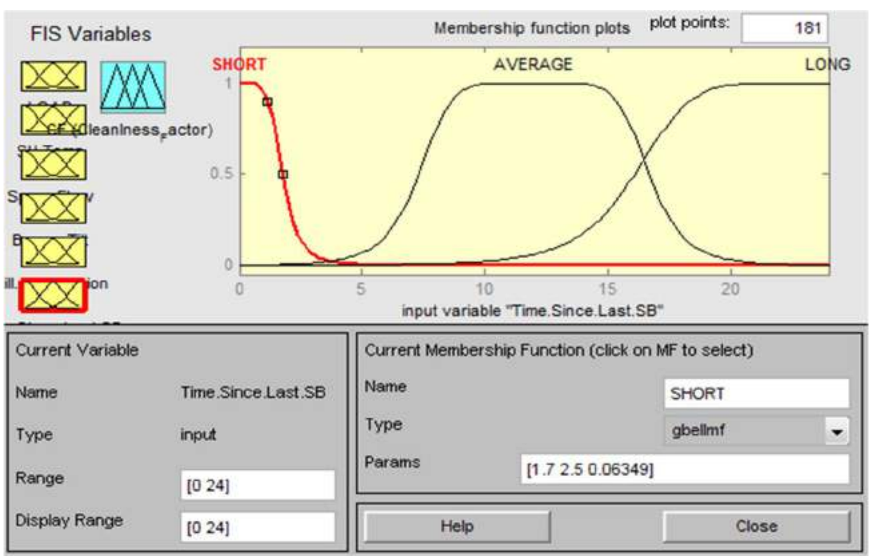


Fig. 10 Time since Last Sootblowing

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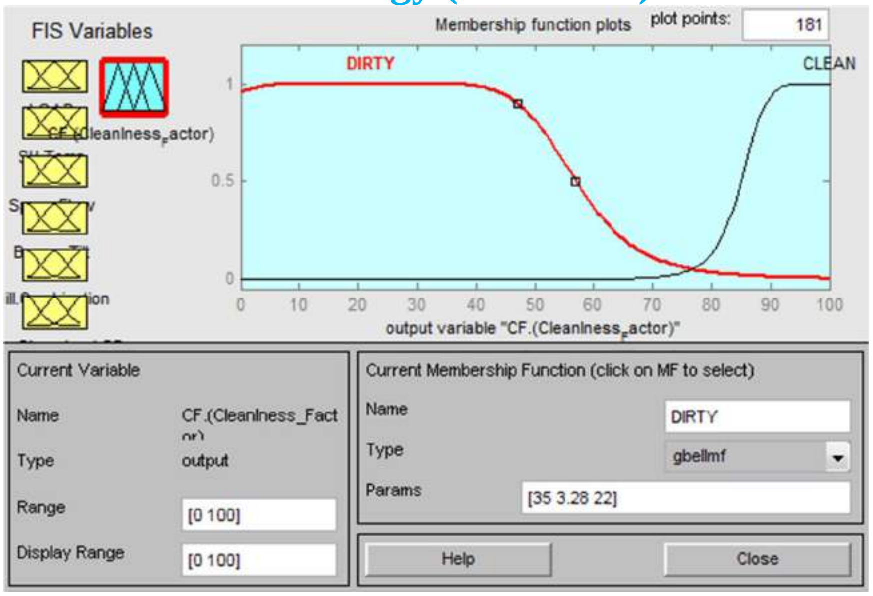


Fig. 11 Cleanliness Factor

The surface view of various input combinations and Command Output ( CF ) is shown in Figure12

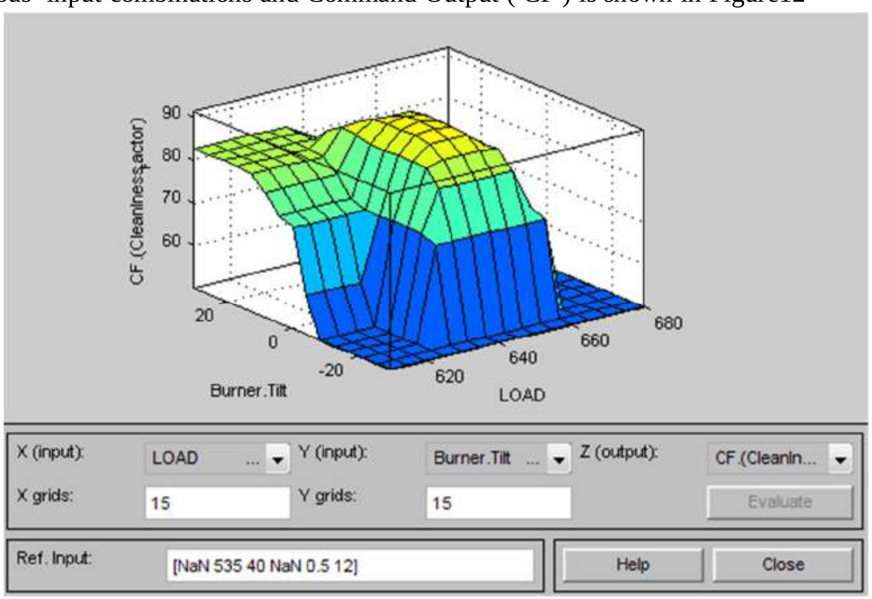


Fig. 12 Surface view of Load, Burner tilt and CF

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, maximize power generation, Minimizes maintenance cost and avoids unmanageable soot build up. The sample results of the MATLAB with six inputs as shown below, estimates the Cleanliness Factor from the Fuzzy Soot Blowing Model.

*A. Results*

Enter LOAD: (MW): 645
Enter SH METAL TEMP (C): 535
Enter TOTAL SPRAY: (T/H): 40
Enter BURNER TILT (degree): 0
Enter MILL COMBINATION: 0.5

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Enter TIME SINCE LAST S/B: 12
CLEANLINESS FACTOR OF THE FURNACE is 91.5

## 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. Results of simulation experiments demonstrate that the Fuzzy algorithm may improve the performance of Sootblowing control loop well beyond that obtained in conventional PID algorithm. Hence, the Fuzzy logic 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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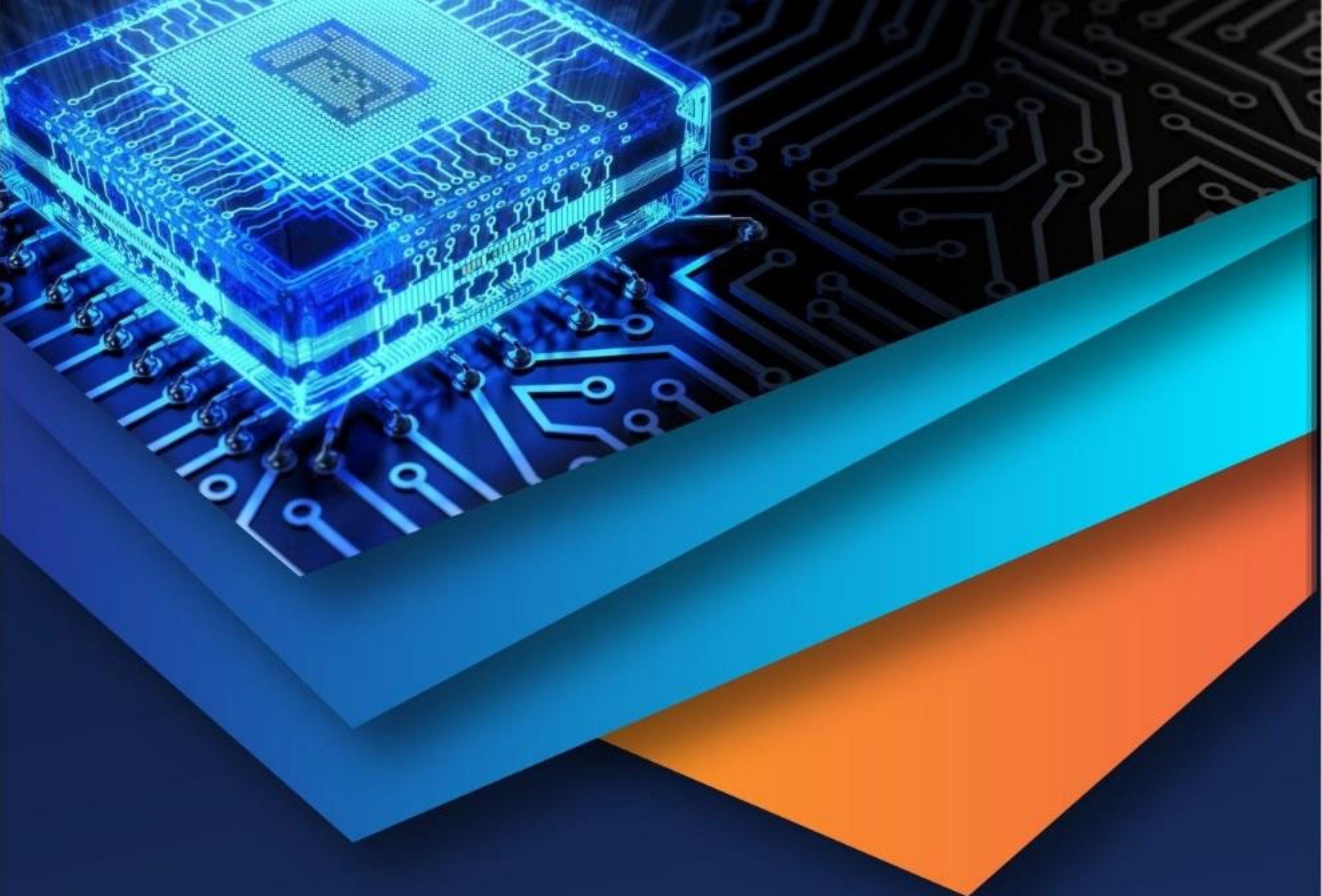


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