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Fuzzy Logic Driven Sliding Mode Controller for Boiler Water Level Control

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ABSTRACT: A stable control of water level in boiler drum is a necessary requirement for safe and efficient operation of ship boiler. Too low water levels may cause overheating of boiler tubes and too high water levels lead to improper separation of water and steam resulting in poor efficiency. As ship boiler is subjected to strong load disturbances, it is challenging to control drum water level. Sliding Mode Controller (SMC) is applied to the system, sliding mode parameters are optimized with fuzzy logic and the results are compared with conventional PID controller and SMC with Adaptive Genetic Algorithm (AGA). It is demonstrated that SMC with fuzzy logic exhibits better transient response in terms of its rise time, settling time and the steady state response.

KEYWORDS: PID controller, SMC (sliding mode control), drum water level, fuzzy logic.

I. INTRODUCTION

Boiler is a closed vessel where steam is produced by the interaction of water in water tubes with hot gases by conversion of stored chemical energy of fuel to heat energy of steam. Boiler being the main part in the ship propulsion system, it is very critical to operate boiler safely and efficiently. Boiler drum water level is an important performance parameter as too low water level may cause overheating of water tubes and too high water level may cause improper functioning of separator resulting in impaired separation of water and steam. During the ship operation, load disturbances are very strong and they will significantly impact the drum water level. In order to overcome this uncertainty of parameters, sliding mode control with soft computing techniques are explored.

Young et al. have presented a comprehensive framework to sliding mode control design solutions [1]. Sliding mode control methodology has been very widely applied in applications like electric drives, position control of DC motor, isothermal chemical process reactors, autonomous under water vehicles [2, 3, 4, 5]. Esfahani et al. have introduced improved sliding mode controller for nonlinear quadruple tank system. In order to reduce chattering effect in conventional sliding mode controller, discontinuous term is replaced by adaptive proportional-differential term and satisfactory results are obtained [6]. Verma et al. have proposed a comparative analysis of control performance of boiler drum level using various classical approaches like cascaded control, internal model control (IMC), feedback-feedforward control and fuzzy logic control (FLC). Results have shown that FLC has better performance versus other approaches [7]. Lingda Kong et al. proposed a control algorithm based on cloud model to adjust PID parameters and the method has realized fast and accurate control for drum water level [8]. A fuzzy logic based feedback controller is proposed to control non-linear dynamic systems like water bath temperature control system to achieve desired response [9]. Dimeo et al. have proposed control system design of boiler-turbine unit using genetic algorithms. The ability of genetic algorithms to develop state feedback controller and proportional-integral (PI) for non linear multi-input and multi-output plant model is explored [10]. Liu Sheng et al. have presented a sliding mode controller with adaptive genetic algorithm (AGA) to control the drum water level of the ship boiler system and have shown that sliding mode controller with AGA leads to better performance than the conventional PID controller [11].

In this paper, a fuzzy logic driven optimized sliding mode control is proposed to control the water level in the boiler drum.

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II. SLIDING MODE CONTROLLER

Sliding mode controller is a nonlinear controller with advantages of order reduction, decoupling of design procedure, insensitivity to parameter variation, accuracy and ease of implementation for functional goals of control. In this methodology, dynamics of nonlinear system is altered by the application of discontinuous control signal that drives the system along the cross section of system stable region rejecting nonlinear behaviour. Sliding mode system are designed to drive the system on a particular surface known as sliding surface, once this is reached sliding mode control keeps the system close to this surface. Sliding mode control consists of two parts: sliding surface and forcing function. Sliding surface defines the region of stability and forcing function forces the system to slide along the stable sliding surface.

A simplified system of ship boiler drum water level model is shown in Fig. 1. The sliding surface is designed by taking error of drum water level, its velocity and its acceleration in to s-function and stability of the surface is verified using Lyapunov Stability Theorem, Forcing function is designed such to drive the system through this stable sliding surface [11].

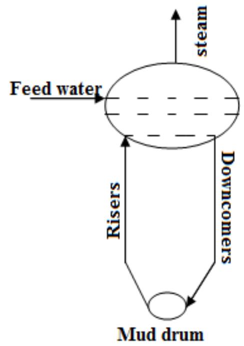

Figure.1: Model of boiler drum water level [11].

III. FUZZY LOGIC DRIVEN SLIDING MODE CONTROLLER

A fuzzy logic driven optimized sliding mode control is proposed to control the water level in the boiler drum. The sliding surface is designed by taking error of drum water level, its velocity and its acceleration in to s-function [11]. Then sliding mode parameter η like in the forcing function is optimized by fuzzy logic. The inputs to fuzzy logic are reference input and the system output. The block diagram of the sliding mode control with fuzzy logic for water level control is as shown in Fig. 2.

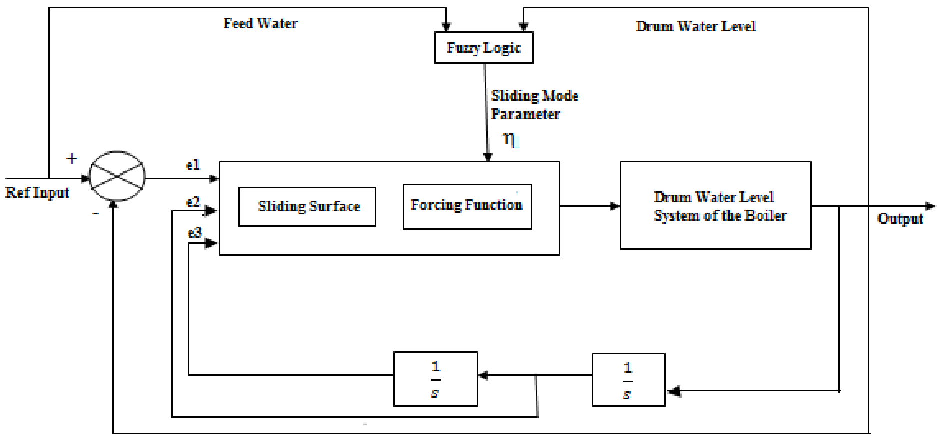

Figure.2: Block diagram of Fuzzy driven SMC.

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Fuzzy logic is a nonlinear control technique, based on if-then rules. Fuzzy logic calculations are based on degree of truth rather than true or false as in the case of Boolean logic. The fuzzy logic implementation involves the following steps: fuzzification, rule evaluation and defuzzification [12].

Fuzzification is the process of converting crisp values to fuzzy variables. This conversation is associated with membership function. A set of if-then statements constitute fuzzy rules that are derived with experience and are evaluated to obtain optimum results. Based on the fuzzy rules, inference system converts fuzzy sets of input values into fuzzy sets of output values. This result is defuzzified to obtain crisp value of SMC parameter $'\eta'$ as output. The flow chart for fuzzy logic implementation is shown in Fig. 3.

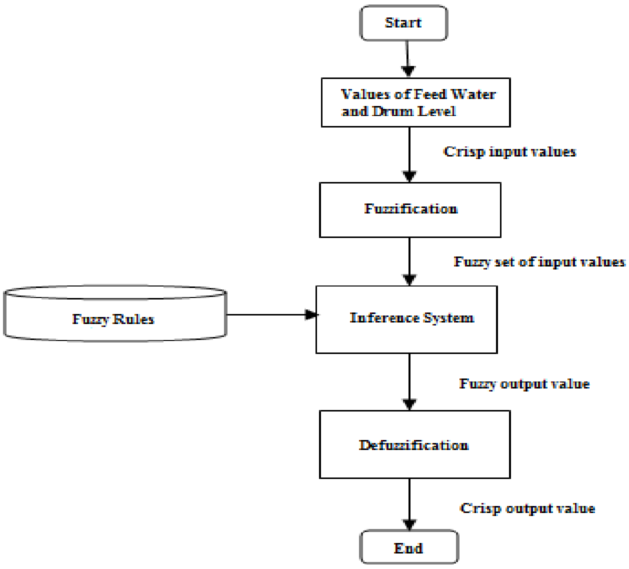

Figure.3: Flow chart for Fuzzy Logic.

Mamdani type of fuzzy logic controller with two inputs and one output is proposed and is as shown in Fig. 4. The two inputs are feedwater reference input and drum water level and the output is $'\eta'$, the SMC parameter.

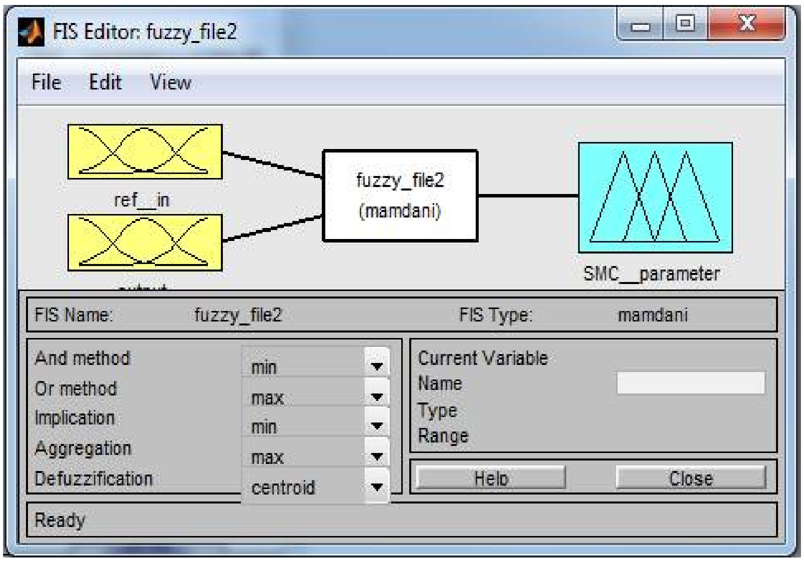

Figure4: Fuzzy logic system

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The centroid defuzzification method is used with the Gaussian membership function defined over the range (-3, 3). Each input and output variables are fuzzified by seven fuzzy sets - Negative Big (NB), Negative Small (NS), Negative Medium (NM), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB). Fig. 5 shows Fuzzy membership function.

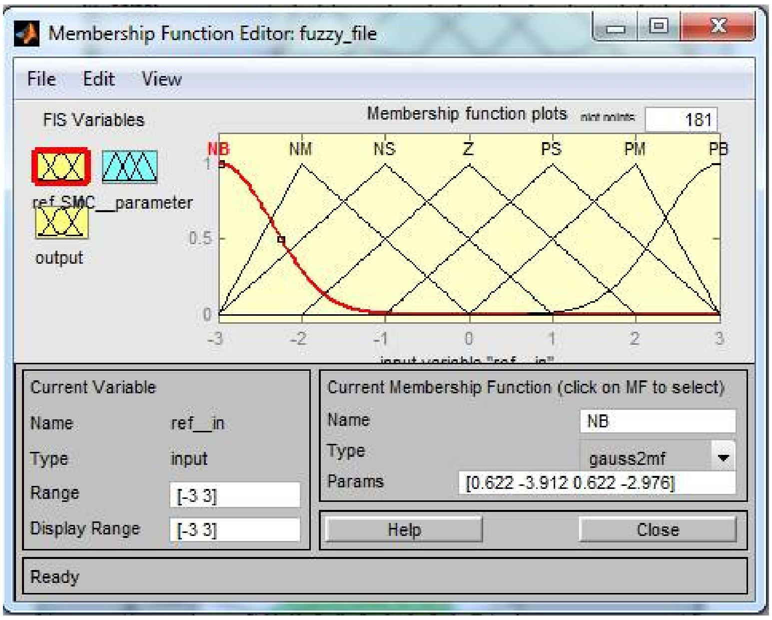

Figure 5: Fuzzy membership function.

In the proposed methodology, input and output variables are fuzzified in seven fuzzy sets and 49 rules are formulated to accomplish the control policy. Fig. 6 shows the generated Fuzzy rule surface.

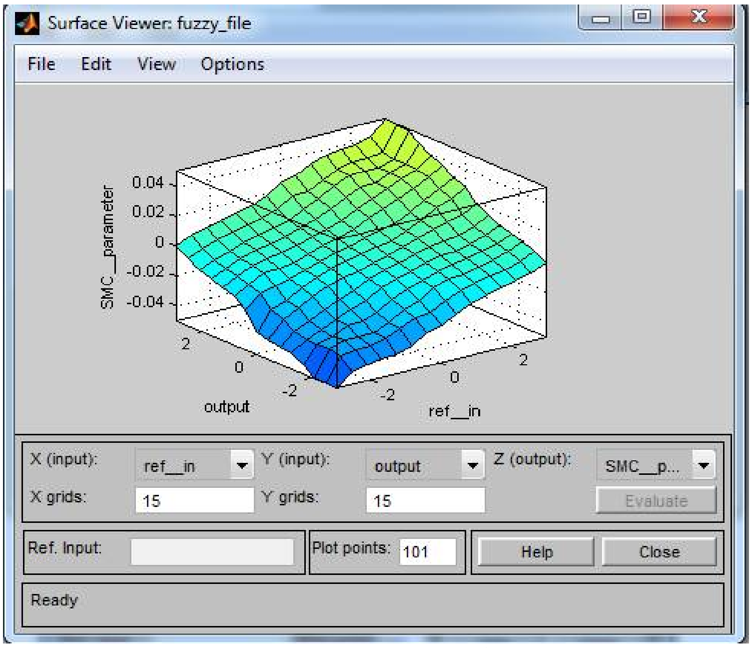

Figure 7: Fuzzy rule surface.

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V. RESULTS AND DISCUSSION

To evaluate the performance of the proposed SMC controller with fuzzy logic, step response is carried out in MATLAB. Fig.8 shows the step response of PID, SMC with fuzzy with respect to the desired response.

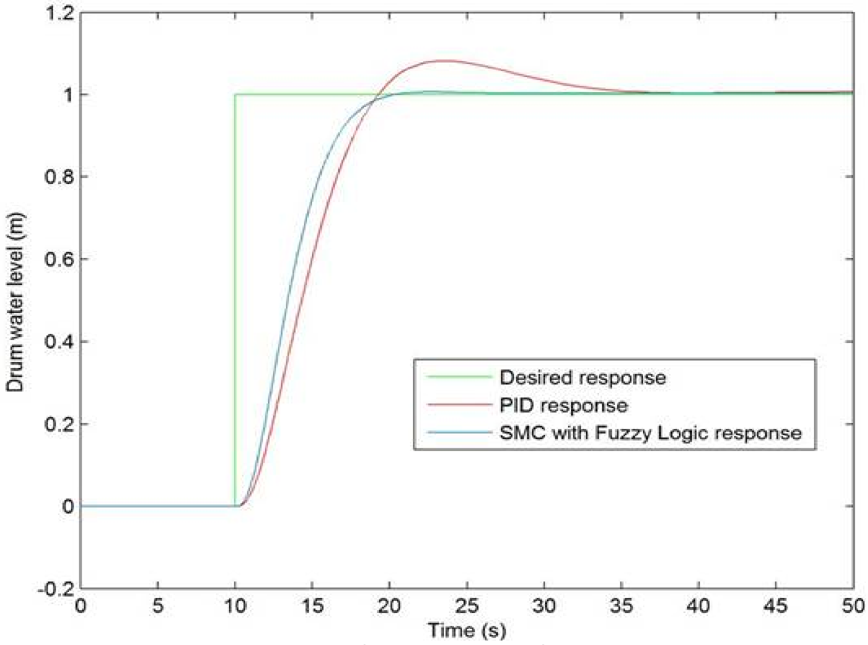

Figure 8: Comparison of step response of various methods.

Table 1: Comparison of time domain response

Type of Controller	Time domain response			
	Rise time(s)	% Max overshoot	Settling time(s)	Steady state error (%)
PID	17.65	8.25	36.6	0.71
SMC with AGA[11]	Not Available	1	26	0
SMC with Fuzzy logic	16.25	0	21.30	0

Table 1 shows the time domain response parameters of various control strategies. It can be seen that SMC with Fuzzy logic has the best response compared to conventional PID control and the SMC with AGA as reported in [11], in terms of rise time, over shoot, settling time and steady state error. Fig.9 shows the desired trajectory of drum water level in response to a sequence of step inputs. It is demonstrated that SMC with fuzzy tracks the desired trajectory better than PID control.

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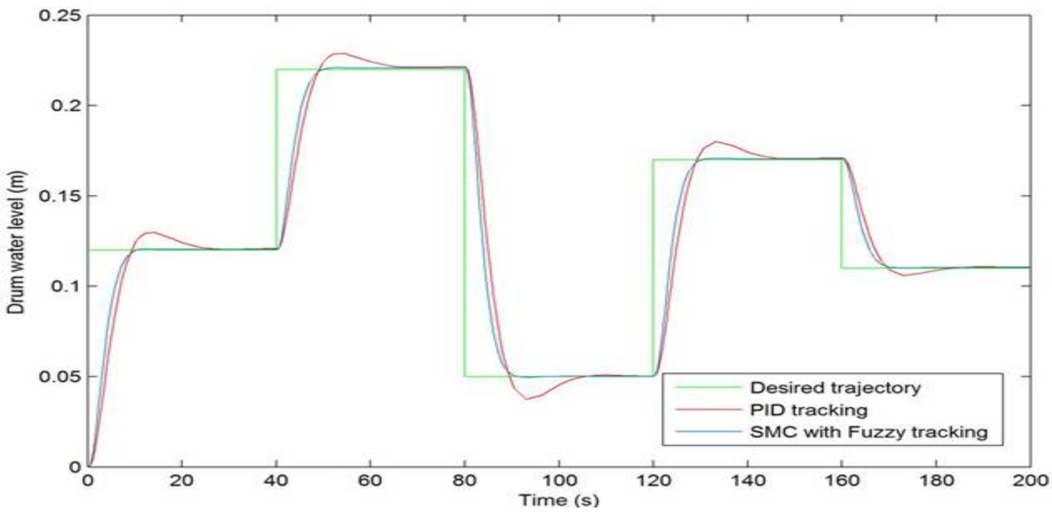

Figure 9: Time response of drum water level in tracking a sequence of step inputs.

VI.CONCLUSION

Boiler drum level is of great importance for safe and efficient operation of boiler. To overcome the serious implications of load disturbances on ship boiler drum level, sliding mode controller with fuzzy logic is proposed. The results are compared with conventional PID and SMC with AGA. Results reveal that sliding mode controller with fuzzy logic exhibits small rise time, small overshoot and better steady state performance. Thus, sliding mode controller with fuzzy can be adopted for drum water level control of ship boiler systems.

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