ISSN : 2231-0711

Boiler Flow Control Using PID and Fuzzy Logic Controller

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Abstract: Conventional Proportional Integral Controllers are used in many industrial applications due to their simplicity and robustness. The parameters of the various industrial processes are subjected to change due to change in the environment. These parameters may be categorized as steam, pressure, temperature of the industrial machinery in use. Various process control techniques are being developed to control these variables. In this paper, the steam flow parameters of a boiler are controlled using conventional PID controller and then optimized using fuzzy logic controller. The comparative results show the better results when fuzzy logic controller is used. Maximum overshoot for fuzzy logic controller is measured as 9.35% as compared with 47.3% given by conventional PID controller. Settling time for fuzzy logic controller and PID controller is measured at 7.18 seconds and 10.14 seconds respectively, which shows the superiority of fuzzy logic controller.

Keywords: boiler, fuzzy logic controller, PID controller.

I INTRODUCTION

The Proportional-Integral-Derivative (PID) controllers have been the most commonly used controller in process industries for over 50 years even though significant development have been made in advanced control theory. According to a survey conducted by Japan Electric Measuring Instrument Manufacturers Association in 1989, 90 % of the control loops in industries are of the PID type. The proportional action adjusts controller output according to the size of the error, the integral action eliminates the steady state offset and the future is anticipated via derivative action. These useful functions are sufficient for a large number of process applications and the transparency of the features lead to wide acceptance by the users. Strength of the PID controller is that it also deals with important practical issues such as actuator saturation and integrator windup. PID controllers perform well for a wide class of processes and they give robust performance for a wide range of operating conditions and are easy to implement using analog or digital hardware. Moreover, due to process uncertainties, a more sophisticated control scheme is not necessarily more efficient than a well tuned PID controller.

The concept of intelligent control lies with the fact that human intelligence is imbibed in to the controller architecture so that human behavior can be emulated in the control decision. Human expert knowledge is based upon heuristic information gained in relation to the operation of the plant or process, and its inherent vagueness ("fuzziness") offers a powerful tool for the modeling of complex systems. The fuzzy logic controller provides an algorithm, which converts the expert knowledge into an automatic control strategy. Fuzzy logic is capable of handling approximate information in a systematic way and therefore it is suited for controlling non linear systems and is used for modeling complex systems where an inexact model exists or systems where ambiguity or vagueness is common. The fuzzy control systems are rule-based systems in which a set of fuzzy rules represent a control decision mechanism to adjust the effects of certain system stimuli. With an effective rule base, the fuzzy control systems can replace a skilled human operator. The rule base reflects the human expert knowledge, expressed as linguistic variables, while the membership functions represent expert interpretation of those variables.

II PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROLLER

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. In the absence of knowledge of the underlying process, PID controllers are the best controllers. However, for best performance, the PID parameters used in the calculation must be tuned according to the nature of the system – while the design is generic, the parameters depend on the specific system. The PID controller calculation (algorithm) involves three separate parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability. Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral value may prevent the system from reaching its target value due to the control action.

III FUZZY LOGIC BASED CONTROLLER

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement. As discussed earlier, the processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". Typical fuzzy control systems have dozens of rules. Consider a rule for a thermostat: IF (temperature is "cold") THEN (heater is "high").

IV PROBLEM FORMULATION

A boiler of a chemical plant is taken as a case study and the temperature control of the boiler is achieved using conventional PID controller and intelligent fuzzy logic based controller. The comparison of both the controller performance is analyzed in this chapter.

Set point

Set point of temperature = 380 degree Celsius.

V. MATHEMATICAL MODELING & CONTROLLER DESIGN

The basic conventional feedback controller is shown in figure 1. In conventional PID controller the controller and the process are in series where as a feedback from the output is given to the input. The boiler of chemical plant is mathematically modeled using experimental data available and the transfer function of the above system is achieved as

$$G(s) = \frac{5(s+1)}{s(s+1)(s+6)}$$

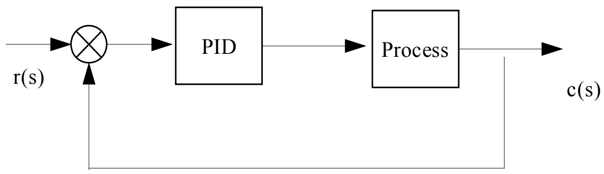

Figure 1: Block diagram of classical control architecture

The stability analysis of the system is done and the bode plot of the system is plotted which is shown in figure 3. The gain margin is 20 db where as the phase margin is 56.2°.

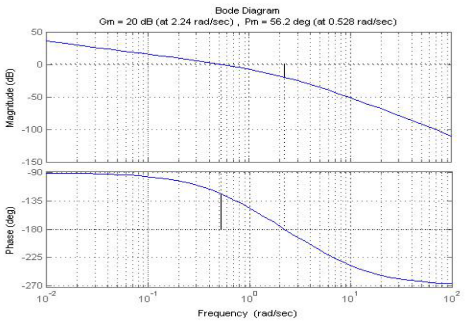

Figure 2: Frequency domain analysis of the system

VI. PID CONTROLLER DESIGN AND TUNING

A feedback control system measures the output variable and sends the control signal to the controller. The controller compares the value of the output signal with a reference value and gives the control signal to the final control element via the actuator.

The characteristic equation obtained as below

$$s^3 + 6s^2 + 5s + K_{cu} = 0 \qquad (1)$$

Applying Routh criteria in eq (1) we get Kcu = 30

From auxiliary equation in routh criteria we get ω = 2.03 and T = 2.69

The equation of ideal PID controller is

$$u(t) = K_c\left(e(t) + \frac{1}{\tau_i}\int_0^t e(t)dt + \tau_d\frac{de(t)}{dt}\right)$$

$$u(s) = K_c\left(1 + \frac{1}{\tau_i s} + \tau_d s\right)e(s)$$

$$u(s) = K_c\left(\frac{1 + \tau_i s + \tau_i\tau_d s^2}{\tau_i s}\right)e(s)$$

The real PID controller is

$$u(s) = K_c\left(\frac{1+\tau_i s}{\tau_i s}\right)\left(\frac{1+\tau_d s}{1+\alpha\tau_d s}\right)e(s)$$

The PID controller is traditionally suitable for second and lower order systems. It can also be used for higher order plants with dominant second order behaviour. The Ziegler-Nichols (Z-N) methods rely on open-loop step response or closed-loop frequency response tests. A PID controller is tuned according to a table based on the process response test. According to Zeigler-Nichols frequency response tuning criteria

$K_p = 0.6K_{cu}$, $\tau_i = 0.5T$ and $\tau_d = 0.125T$

For the PID controller in the heat exchanger, the values of tuning parameters obtained are K_p=32, τ_i=1.5, τ_d=0.29 and P= 30, I= 21.2, D=9

Usually, initial design values of PID controller obtained by all means needs to be adjusted repeatedly through computer simulations until the closed loop system performs or compromises as desired. This stimulates the development of "intelligent" tools that can assist the engineers to achieve the best overall PID control for entire operating envelops.

VII. BOILER CONTROL USING FUZZY LOGIC CONTROLLER

PID controller is a standard control structure for classical control theory. But the performance is greatly distorted and the efficiency is reduced due to nonlinearity in the process plant. The fuzzy PID controllers are the natural extension of their conventional version, which preserve their linear structure of PID controller. The fuzzy PID controllers are designed using fuzzy logic control principle in order to obtain a new controller that possesses analytical formulas very similar to digital PID controllers. Fuzzy PID controllers have variable control gains in their linear structure. These variable gains are nonlinear function of the errors and changing rates of error signals. The main contribution of these variable gains in improving the control performance is that they are self- tuned gains and can adapt to rapid changes of the errors and rate of change of error caused by time delay effects, nonlinearities and uncertainties of the underlying process.

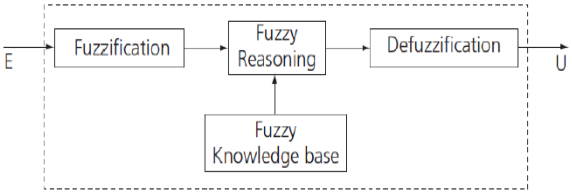

Figure 3: Architecture of fuzzy control

In this paper we have considered different linguistic variables and details of these variables are shown in table 1.

Table 1: Linguistic variable of fuzzy logic control

Error e(t)		Change in error Δe(t)		Controller output u(t)	
NB	Negative Big	NB	Negative Big	NB	Negative Big
NM	Negative Medium	NM	Negative Medium	NM	Negative Medium
NS	Negative Small	NS	Negative Small	NS	Negative Small
ZO	Zero	ZO	Zero	ZO	Zero
PS	Positive Small	PS	Positive Small	PS	Positive Small
PM	Positive Medium	PM	Positive Medium	PM	Positive Medium
PB	Positive Big	PB	Positive Big	PB	Positive Big

Designing a good fuzzy rule base is the key to obtain satisfactory control performance for a particular operation. Classical analysis and control strategy are incorporated in the rule base. The rule base used in simulation is summarized in Table II. Each rule has the form IF e(t) is NB AND Δe(t) is NB THEN u(t) is NB. The control literature has worked towards reducing the size of the rule base and optimizing the rule base using different optimization techniques like GA, PSO for intelligent controller. At last defuzzified output is obtained from the fuzzy inputs. In this research work centroid method of de fuzzification is used. It is given as below.

$$u^* = \frac{\int \mu_c(u) * u\,du}{\int \mu_c(u)\,du}$$

Table 2: IF-THEN rule base for fuzzy logic control

u(t)		e(t)						
		NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
Δe(t)	**NB**	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	NS	PS	PS
	ZO	NB	NM	NS	ZO	ZO	PM	PM
	PS	NM	NS	ZO	PS	PS	PB	PB
	PM	NS	ZO	PS	PM	PM	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

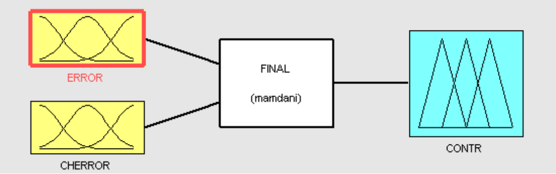

Figure 4: Mamdani fuzzy inference system developed for fuzzy controller

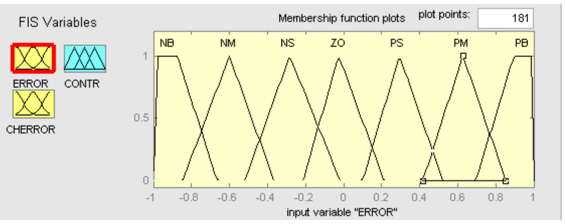

Figure 5: Triangular and trapezoidal input membership function for input (error)

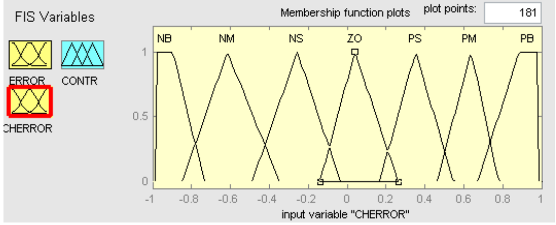

Figure 6: Triangular and trapezoidal input membership function for input (cherror)

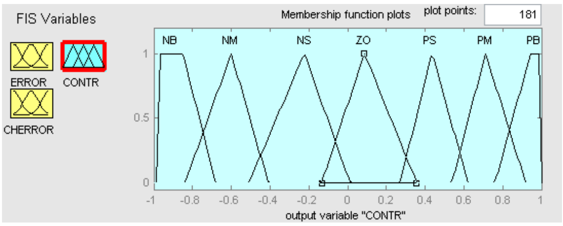

Figure 7: Triangular and trapezoidal input membership function for output (contr)

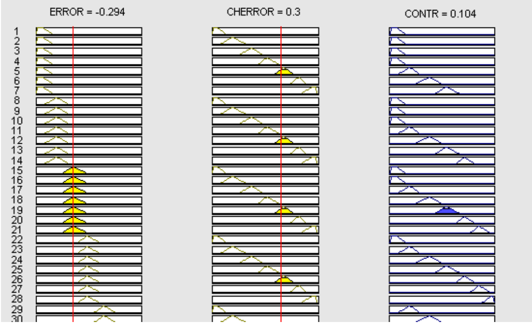

Figure 8: Rule viewer for fuzzy inference system

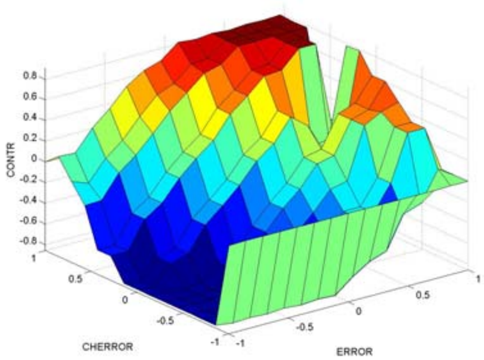

Figure 9: Surface view of FIS

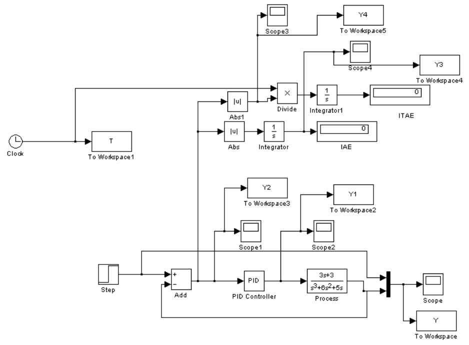

Figure 10: Simulink representation of feedback control

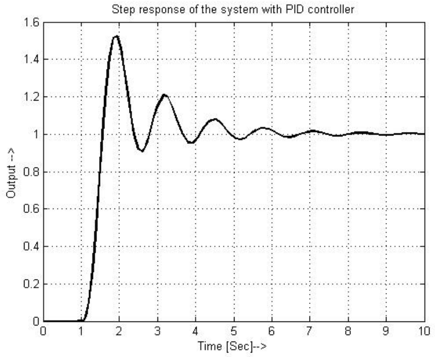

Figure 11: Step response of process with feedback PID controller

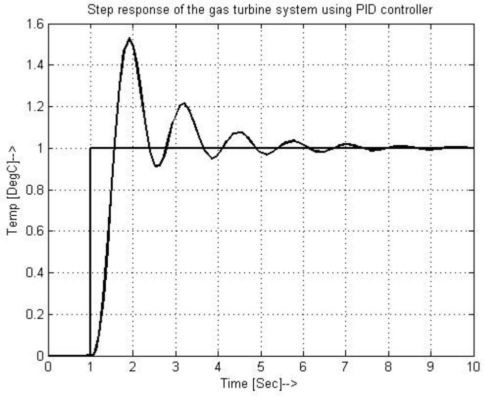

Figure 12: Step response of the system with input and output

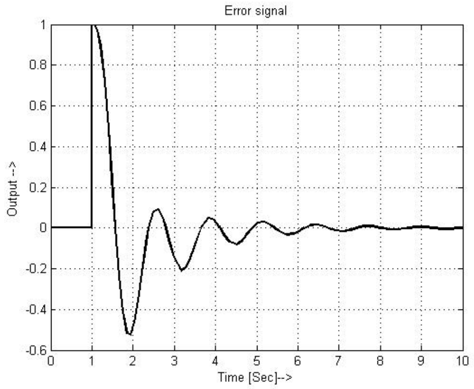

Figure 13: Graph for error signal

VIII. SIMULINK REPRESENTATION OF BOILER CONTROL USING FUZZY LOGIC CONTROLLER

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Boiler control using simulink is modeled as given below:

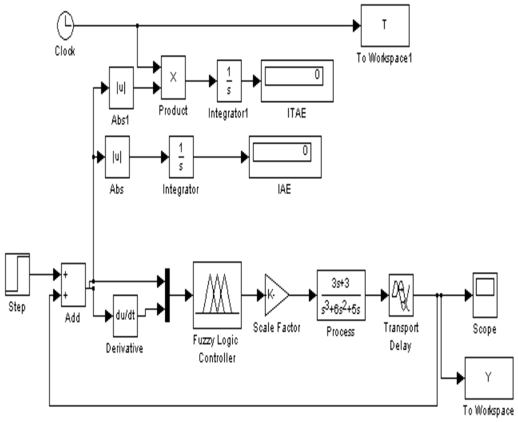

Figure 14: Simulink representation of system with fuzzy logic controller

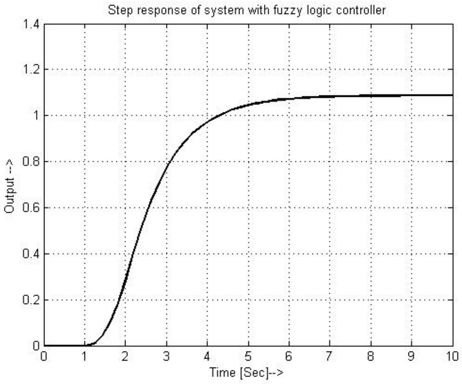

Figure 15: Step response of system with fuzzy logic controller

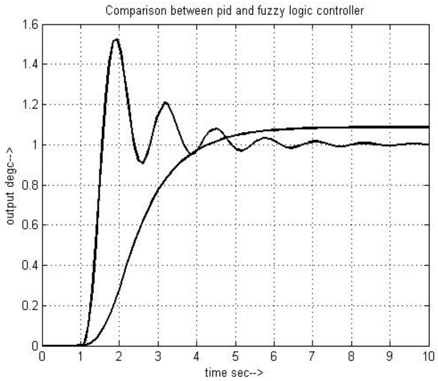

Figure 16: Comparison between PID controller and fuzzy controller

This section shows a comparative study between different controllers. In this paper we have considered the steady state and transient state parameters. These parameters are maximum overshoot, settling time.

Table 3: Comparison of Maximum overshoot and settling time for conventional PID controller and fuzzy logic control

S. No	Controller	Maximum Overshoot	Settling Time
1	PID Controller	47.3%	10.14 sec
2	Fuzzy logic controller	9.35%	7.18 sec

Table 4: Comparison of Integral of Absolute Error (IAE) and Integral of Time and Absolute Error (ITAE) for PID controller and FLC

S. No	Controller	IAE	ITAE
1	PID Controller	0.86	1.72
2	Fuzzy logic	15.72	97.19

VII CONCLUSION

In this paper a process control case study taking boiler has been implemented. The flow of high pressure steam to the turbine is controlled by electronic governor. First of all a mathematical model of the system is developed and a conventional PID controller is implemented in it. The PID controller gives a very high overshoot and high settling time. So we proposed and implemented artificial intelligence principles in the controller architecture. Then we implemented a fuzzy logic control and then optimized the step response parameter using genetic algorithm. The fuzzy logic control gives a much better response then the conventional PID controller. In future scope we can implement neural network based feed forward controller and genetic algorithm based online optimization techniques to improve the control performance.

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