

SMART SUPERVISORY SYSTEM FOR THERMAL POWER STATION

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Abstract – An intelligent supervisory system for thermal power station is proposed. In this method, the energy input to the boiler would be matched to the energy demand by the turbine generator. The existing control schemes have difficulty to cope up with inherent time delay, nonlinearity due to uncertainty of the combustion process and frequent load changes. This paper presents the design of fuzzy controllers for boiler to turbine coordination during normal load change operation and turbine to boiler coordination during sudden change in demand. The coordinated control will give set value for air/fuel controller for combustion process and throttle valve positioner to control the steam flow to the turbine inlet at all loads. A lab scale simulators were fabricated tests were conducted for various load conditions. The advantages of the proposed system are highlighted.

I. INTRODUCTION

In a thermal power station, steam is produced in a boiler, is expanded in the prime mover (turbine) and condensed in a condenser before feeding it into the boiler again. The turbine shaft is coupled with generator, which is used to produce electricity.

Many control configurations [1] are used in a Thermal plant for coordinated operations are 1) turbine-following mode (constant boiler pressure): the component load command adjusts the fuel supply to the boiler and then turbine admission valves control the boiler pressure. 2) Boiler following mode (sliding boiler pressure): the component load command adjusts the turbine admission valves by means of the speed or power controller and then steam pressure is controlled by the fuel supply to the boiler. 3) Unit coordinated mode: the component load command is applied simultaneously to both, the turbine admission valves and the fuel supply system[1-5], the steam pressure is trimmed by the turbine admission valves and/or by the fuel supply to the boiler.

Conventional Proportional-Integral-Derivative (PID) controller used for the control is simple in structure, reliable in operation and robust to certain extent in performance. But it is not generally suitable for non-linear, higher order, time delayed and complex systems that have no precise mathematical models. Further it needs frequent tuning, which is not an easy task and is also time consuming. Several methods of tuning were suggested for the PID controller schemes [2,3].

In order to cope up with varying dynamics of the system, PID controllers have been evolved to include adaptive features such as gain scheduling and self-tuning. Adaptive control schemes [4] automatically adjust their control characteristics under various operating conditions in order to maintain effective control of a process. During the last

decade, extensive research had been carried out on adaptive control theory, methods and applications. Feng et al. [5] have proposed adoptive algorithm for PID controllers based on a theory of adaptive interaction. Aidan O'Dwyer et al. [6] have proposed a classification of techniques for the compensation of time delayed processes with parameter optimized controllers. Christis C. et al. [7] have proposed a deterministic adaptive control based on laguerre series representation. Ed.bancalari. et al.[8] have dealt with adaptation of SGT6-6000G gas turbine to a dynamic power generation market. Palmor Z.J [9] has proposed boiler following control configuration for drum type boiler. After the introduction of fuzzy logic by L.A.Zadeh, many researchers applied it for several real time control applications. Even though many mathematical models are formulated for power plant [10-15], fuzzy systems are being used successfully in increasing number of applications. They use linguistic rules to describe systems. These rule-based systems are more useful for complex systems where it is difficult to describe the system mathematically. Lu Jianhong; Chen Laijiu; Zhao Sujin; Wu Yiqian, et al. [16] developed a Multivariable fuzzy Pid control system For deaerator's and condenser's levels in a thermal powerunit.

Young-Moon Park et al. [17] have proposed a self-organizing fuzzy controller for dynamic system using autoregressive moving average (FARMA) model. Al Ghaffar et al. [18] have proposed application of fuzzy logic to steam power plants. Jong-Wook Kim et al.[19] proposed the design of incremental fuzzy PI controllers for a gas turbine plant. Ali Ghaffari, A. Hosein Shamekhi, Akbar Saki and Ehsan Kamrani et al.[20] proposed Adaptive Fuzzy Control For Air-Fuel Ratio Of Automobile Spark Ignition Engine.

The present work deals with the coordinated control using conventional PID and fuzzy scheme applied to the air flow and fuel flow to control the combustion process of boiler and throttle position to control the steam inlet to the turbine as per the demand in a thermal power plant. This paper is organized as follows: Section 2 deals with the lab scale simulators for boiler, turbine, generator and electrical interlock for the generator, lab scale experimental set up for fuel, air and throttle controller[21-25]. Section 3 deals with conventional coordinated boiler follow and turbine follow mode controls, Section 4 presents the proposed fuzzy controller for airflow, fuel flow and throttle position. Section 5 deals with the results & discussion and Section 6 describes the summary & conclusions.

II. LAB SCALE SIMULATOR AND EXPERIMENTAL SETUP

The lab scale simulator setup for boiler, turbine, generator, electrical interlock for generator and lab scale experimental set up air/fuel flow control and throttle valve control are fabricated and interfaced with the computer.

The basic simulation software was developed using C++ language, under the Windows environment[26-30], enabling to simulate load, speed, turbine inlet steam flow, turbine inlet throttle pressure, drum pressure, valve position of steam, fuel and air flow under various operating conditions.

The simulation system was loaded with the following performance based responses collected from 210 MW thermal power station[31-35]. 1) Load vs. turbine flow, 2) Load vs. turbine first stage pressure, 3) Steam flow vs. oxygen in flue gas, 4) Load vs. fuel flow and 5) Load vs. airflow. And also the energy balance, heat rate, combustion equations and performance calculation were loaded.

III. CONVENTIONAL COORDONATED BOILER AND TURBINE FOLLOW MODE CONTROL

In coordinated boiler-follow turbine inlet, the load controller generates the demand to the turbine inlet steam throttle valve from the unit load demand and the measured generated power, and then pressure controller generates the demand to the fuel/air valves for combustion process of boiler from the measured throttle pressure and the pressure set point[42-45].

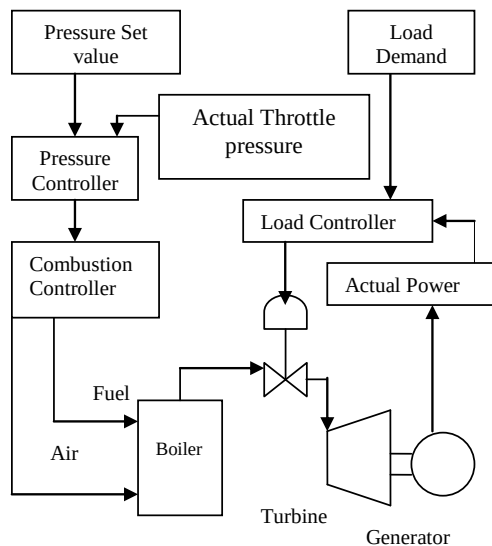


Figure 1. Boiler Follow Mode

In coordinated turbine-follow mode[36-41], the load controller generates the demand for the fuel/air valves from the unit load demand and the measured generated power.

Then demand to the throttle valve is calculated from the measured throttle steam pressure and the pressure set point. The schematic diagram for coordinated boiler-follow mode and coordinated turbine-follow mode are shown in Fig.1 and Fig.2. Using simulator the set point for air fuel for combustion control and throttle valve position controller were derived. The operation methodology for conventional controller is shown in Fig.3. For normal loading is controlled through boiler to turbine coordinator and for sudden load disturbance is controlled through turbine to boiler coordinator.

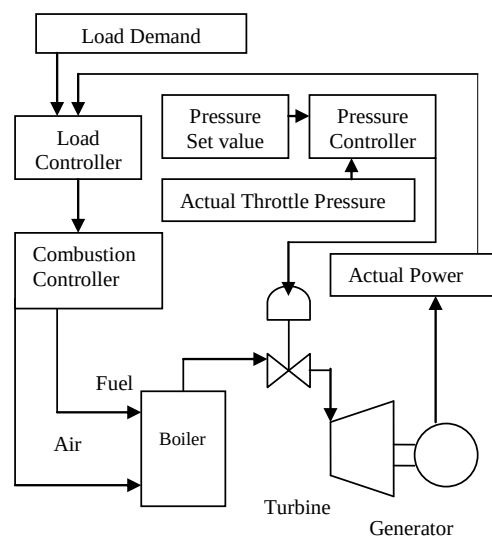


Figure 2. Turbine follow mode

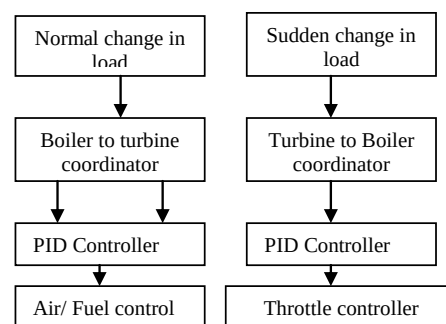


Figure 3. Operational methodology of conventional PID controller

The optimum PID controller parameters for air, fuel and throttle controllers were obtained by trial and error from the simulation test conducted in the lab scale experimental setup for various load conditions with respect to real time data collected from thermal power plant are presented in Table I.

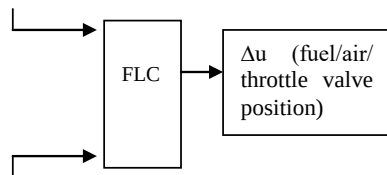
TABLE I
OPTIMUM PID PARAMETERS

Control loop	Cascaded PID parameter		
	K_p	K_i	K_d
Fuel Controller	1.75	1.0	0.2
Air Controller	1.5	0.8	0.2
Throttle Controller	2	1.5	0.5

IV. PROPOSED FUZZY CONTROLLER FOR AIR/ FUEL FLOW AND THROTTLE CONTROLLER VALVE

Separate fuzzy logic controllers (FLC) implemented [22] for boiler-follower mode and turbine-follower mode for normal and sudden load change conditions to control fuel flow, air flow and throttle valve position. The proposed fuzzy controller system for fuel, air throttle control is shown in the Fig.4.

e (fuel /air flow/load)



Δe (fuel/air flow/load)

Figure 4. FLC for fuel/air/throttle control

FLC has two inputs and one output for fuel, air and throttle pressure respectively. The inputs are error (e) and change in error (Δe) and the output is the change in controller position (Δu). The universes of discourse of the controller variables are E , ΔE and ΔU respectively.

$$e_k = r_k - y_k \quad (1)$$

$$\Delta e_k = e_k - e_{k-1} \quad (2)$$

$$\Delta u_k = u_k - u_{k-1} \quad (3)$$

The number of linguistic terms for each linguistic variable is 5. Triangular membership functions were used to represent the meaning of the linguistic terms of the controller variables

(NB=Negative Big, NS=negative Small, ZE=Zero, PS=Positive Small and PB= Positive Big.) Their value range is – 10 to +10.

The rules are in the form:

$$\text{If } e_k \text{ is NB, and } \Delta e_k \text{ is PS then } \Delta u_k \text{ is NS} \quad (4)$$

The combination of rules can be expressed mathematically by its membership function as:

$$\mu_R N(e, \Delta e, \Delta u) = f_1[\mu_{R^1}(e, \Delta e, \Delta u), \dots, (\mu_{R^n}, \Delta e, \Delta u)] \quad (5)$$

where

$R^1, R^2, \dots, R^n$ Set of rules and f_1 is the ELSE connective.

In equation (5) each rule 'j' can be expressed as:

$$\mu_{R^j}(e, \Delta e, \Delta u) = f_2[f_3(\mu_{E^j}(e), \mu_{\Delta E^j}(\Delta e), \mu_{\Delta U^j}(\Delta u))] \quad (6)$$

In equation (6), $E=(e)$, $\Delta E=(\Delta e)$, $\Delta U=(\Delta u)$ are the finite universes and E^j , ΔE^j and ΔU^j are the fuzzy subsets of those universe. f_2 and f_3 are implication and interpretation of connective AND ($\min \wedge$).

The controller output fuzzy set U_s is:

$$\mu_{U_s}(\Delta u) = f_1[f_2\mu_{E^1}(e_s) \wedge \mu_{\Delta E^1}(\Delta e_s), \mu_{U^1}(\Delta u), \dots, f_2\mu_{E^n}(e_s) \wedge \mu_{\Delta E^n}(\Delta e_s), \mu_{U^n}(\Delta u)] \quad (7)$$

Defuzzified (crisp) value $= \Delta U_{\text{crisp}}$

An inference mechanism is designed using Mamdani (min-max) method (The values inside the rule base matrix correspond to the manipulated variable) that gives the output signal. The output of the inference mechanism is a fuzzy value and is converted into crisp value using center of area method of defuzzification and applied to the respective control valves positioner.

The rule base matrix for the proposed fuel/air and throttle controller is presented in Table.II.

TABLE II FUZZY RULE MATRIX FOR ΔU

$\Delta e/e$	NB	NS	ZE	PS	PB
NB	NB	NB	NM	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PB
PS	NS	ZE	PS	PS	PB
PB	NS	PS	PS	PB	PB

V. RESULTS AND DISCUSSIONS

A novel method for fuel, air and throttle control for coordinated controller using PID and fuzzy schemes were proposed. Several tests were carried out in the lab scale experimental set up. Simulation results show that the proposed fuzzy design is able to achieve zero steady state

error taking very less settling time without much over shoot and under shoot. The proposed design also has the ability to accommodate and account for the change in the dynamics due to sudden load change, without much time delay.

Control Loop	Control Scheme	Setl. Time	ISE	IAE
110-63 MW Fuel flow	PID	92	9694	9565
	Fuzzy	61	7212	8112
Air flow	PID	96	9412	9672
	Fuzzy	46	7416	7134
Throttle position	PID	128	9811	8842
	Fuzzy	91	9013	8102

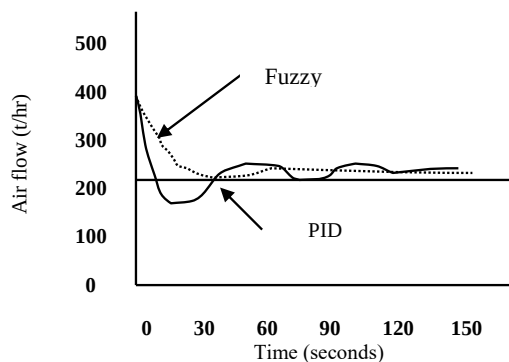


Figure 5. Air (Load 110 MW-63MW)
air flow set point 380 -240 t / hr

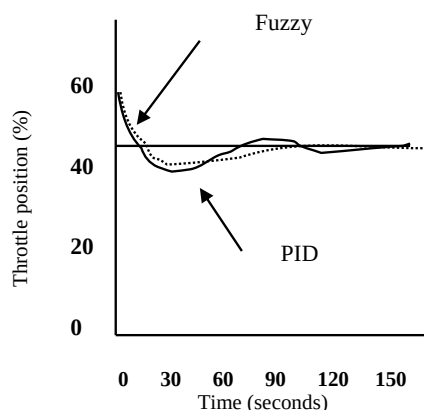


Figure 6. Throttle valve (Load 110 MW-63MW)
set point 58 – 44%

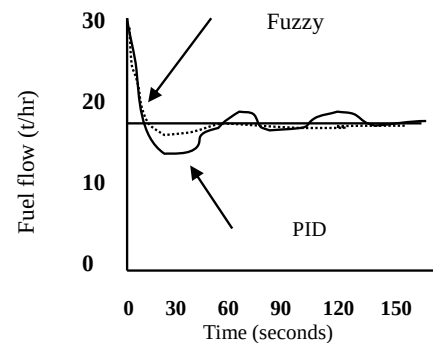


Figure79. Fuel (Load 110 MW-63MW)
Fuel flow set point 29-18 t/hr

Figs. 5-7 show the responses for PID and fuzzy control schemes for a load changes given with respect to steady state values for fuelflow, airflow and throttle position. Table.II presents the comparison of time domine specification and performance for PID and fuzzy control schemes.

From Table II, it is observed that the proposed fuzzy scheme has less settling time, minimum integral square error (ISE) and integral absolute error (IAE) when compared with conventional controller

TABLE. II
COMPARISONS OF PERFORMANCES

VI. SUMMARY AND CONCLUSIONS

This paper presented coordinated controller for both conventional PID and Fuzzy based controllers for a thermal power plant. A lab-scale simulators and experimental set-up designed and fabricated. The control schemes namely conventional PID and fuzzy were designed and real time simulations were carried out on the experimental set-up. The robustness of the fuzzy control scheme is demonstrated for changes in the set point as well as in the load perturbation. The performance of all the control schemes are validated quantitatively using both time domain specifications as well as error integral criterion. The PID controller settles down after about 106, 89 and 94 steps of increment for fuel, air and throttle position respectively. The closed loop response of fuzzy scheme shows satisfactory transient response with out much overshoot and settles down after about 62, 71 and 66 steps of increment fuel, air and throttle position respectively. This shows 30% improvement over conventional schemes in settling time. The control output is smooth without any oscillations, which would increase the life of the control elements. The proposed fuzzy scheme, results in, least ISE and IAE values for changes in load showing 16% improvement for fuel, 14% improvement for air and 22%

improvement for throttle position control when compared to conventional scheme. The qualitative and quantitative comparisons of the performance reveal the superiority of the proposed fuzzy controller over the conventional scheme.

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