A FUZZY PI CONTROLLER APPLICATION IN BOILERS OF THERMAL POWER PLANTS

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ABSTRACT

Nowadays, instead of conventional control techniques, modern control techniques have been implemented for a lot of industrial models practically or theoretically. In this study, a fuzzy logic-based control technique to regulate the power and enthalpy outputs in a boiler of a 765 MW coal-fired thermal power plant was carried out. For comparison, a conventional proportional, integral and derivative (PID), a fuzzy logic (FL) and a fuzzy gain scheduled proportional and integral (FGPI) controllers have been applied to the power plant model. The simulation results show that the FGPI controller developed in this study performs better than the rest controllers on the settling time and overshoot of power and enthalpy outputs.

I. INTRODUCTION

The dynamic behavior of industrial plants heavily depends on disturbances and in particular on changes in operating point. This is particularly the case for large coal fired power plants [1]. Such plants represent from the control engineering point of view a time-variant and nonlinear multivariable process with strong interactions. Therefore, they are very difficult to control [2].
Power plants have some inputs and outputs. The main input variables of a thermal power plant are fuel flow, feed water, injection water and air. The outputs of the system are electrical power, steam pressure, steam temperature, and combustion gas as shown in Figure 1. Some of the inputs and outputs are more important than the others since these are adequate for modeling the power plant. These are coal feed and feed water flow as the inputs, and the electrical power and steam enthalpy as the outputs [1] in Figure 1. Power plant is a multivariable dynamic system. Most of the thermal power plants have been controlled by conventional controller techniques, especially conventional PID controller for many years since these controllers are easy to implement on systems due to their simple structures. However, changing the power demands, quality differences of the coal and contamination of the boiler heating surfaces are problem for controlling the system outputs with conventional controllers. In addition, although there is a reduced mathematical model of a power plant, it is usually non-linear, time-variant and governed by strong cross-coupling of the input variables. All these problems are removed by using advanced control techniques [3]. One of the major techniques is fuzzy logic control. There have been many improvements in the theory of this controller design during the last decades. Consequently, this technique has been widely used on power plants [4,5,6,7,8].

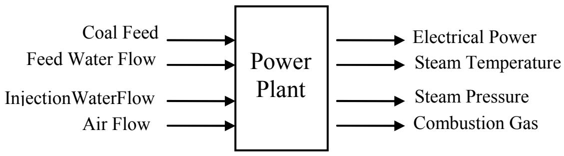

Figure 1. Power plants as multivariable dynamic system

In this paper, three different control techniques were applied to regulate the power and enthalpy outputs of the thermal power plant comparatively. These are a PID controller, a fuzzy logic controller (FLC) and a fuzzy gain scheduled PI controller (FGPI). *The simulation results show that the FGPI controller developed in this study performs better than the rest controllers on the settling time and overshoot of power and enthalpy outputs.*

II. MODELLING THE POWER PLANT

The investigated plant represents a 765 MW combinational block consisting of a generator/steam turbine unit providing 652.5 MW electrical power due to a coal fired once-through boiler with live steam at 195 bar and 535 ^{0}C and another generator/gasturbine unit providing 112.5 MW electrical power. Pulverized coal is fed to 32 burners which are arranged in 4 layers. It is necessary that air for the combustion is supplied by two ventilators. The outlet gases of the turbine are used as heat and oxygen carrier for the succeeding steam boiler. In order to avoid excess air within the furnace for working points between 30 % and 55 % of the full power, the gas turbine outlet gases are deviated and added finally before the intermediate superheater. The power plant consists of boiler, turbine and generator. The boiler can be modeled by a strongly coupled multivariable system. This makes it very interesting from a control engineering point of view. In the boiler, the chemical energy is converted to thermal energy. The dynamic behavior of a boiler heavily depends on many different operating conditions, as explained below:

- the quality and thus the calorific value of the coal changes and this results in changes in the enthalpy and pressure of the live steam as well as that of the generated power;
- the effiency of the coal feeder decreases in time;
- drying of heating surfaces, burners, feeders etc. cause changes in the system dynamics;
- changes in reference variables and load represent changes in the operating point;
- changes of the outlet temperature of the gas turbine in a combinational power station block due to climatic changes may strongly influence the boiler dynamics.

The dynamic and static properties of the system must be well known to design an efficient controller. On the other hand, it is complicated to handle such a complex system with several inputs and outputs. Therefore the most important input and output variables will be used for model buildings. For the investigated power plant, two input and two output variables are sufficient to describe the desired process behavior. As shown in Figure 1, the coal feed and feed water flow are chosen as input variables. The output variables are electrical power and steam enthalpy. The power plant operates at natural balanced pressure mode. By this operation the heat storage of the boiler cannot be used. The speed of power change depends on only the steam generator. That means, by this operation, the steam generation immediately influences the generated electrical power, which is important for the user. The enthalpy of the steam at the outlet of the evaporator seems to be the best measure for system quality because it reacts very fast to heating disturbances and is not affected by injection water. Therefore it has been chosen as the second output variable. The enthalpy is directly influenced by changes of the feedwater flow and coal feed flow [7]. Control diagram of the power plant model is shown in Figure 2. In this figure, three controllers having different structures are used to control the outputs. These controllers were applied to the system one by one. For this reason, first a PID and following a FL controller and finally a FGPI controllers were applied to the power system as power and enthalpy controllers.

III. PID CONTROLLER

The parameters of the conventional PID controllers was determined by system response curve method and after that they were optimized by simulation to use appropriate control parameters. Therefore, K_P=13.96, K_I=0.168 and K_D=51.06 were taken for the power controller whereas for the enthalphy controllers, K_P=15.506, K_I=0.228 and K_D=61.60 were taken.

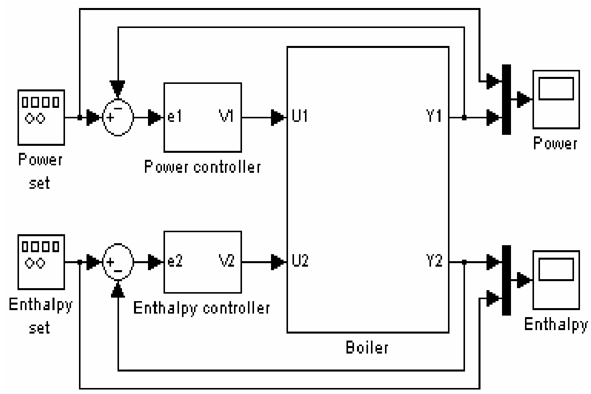

Figure 2. Control diagram of the power plant model

IV. FUZZY LOGIC CONTROLLER

In the proposed power plant, two different fuzzy logic controllers are used for power and enthalpy outputs, separately. Inference mechanisms of the fuzzy logic controller are realized by seven rules. In addition, defuzzification has been performed by the center of gravity method in the studies. The rules which are belong to the membership functions are written in the same way for each fuzzy logic controller. The rules are formed based on the error (e) and its time derivative (de). If the e is highly bigger than the set value and de is increased rapidly then the output of the controller V is also has to be big. Therefore, u is increased and output of the system is goes to the set value. In this work, the appropriate rules are given in Table 1[9]. Names of the abbreviation in Table 1 are NB (Negative Big), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big) respectively. Fuzzy logic shows experience and preference through membership functions. These functions have different shapes depending on system experts' experience [10].

Table 1. Fuzzy logic rules for power and enthalpy outputs

e \ de	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NB	NM	NM
NM	NM	NM	NM	NM	NM	NS	NS
NS	NS	NS	NS	NS	NS	Z	Z
Z	Z	Z	Z	Z	Z	PS	PS
PS	PS	PS	PS	PS	PS	PM	PM
PM	PM	PM	PM	PM	PM	PM	PB
PB	PB	PB	PB	PB	PB	PB	PB

The membership function sets for errors (ei), derivative errors (dei) and decoupling unit inputs (Vi) are shown in Figure 3 and fig-4. Figure 3 is belong to the fuzzy logic controller output for power and Figure 4 is belong to the fuzzy logic controller output for enthalpy.

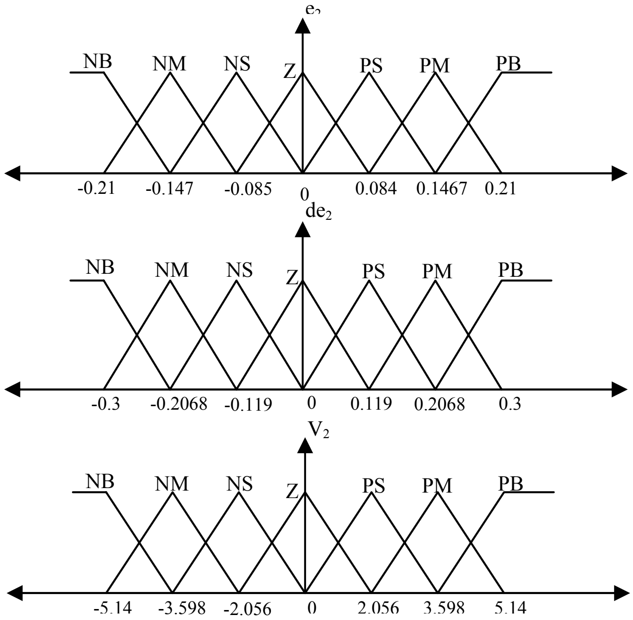

Figure 3. The membership functions of the power

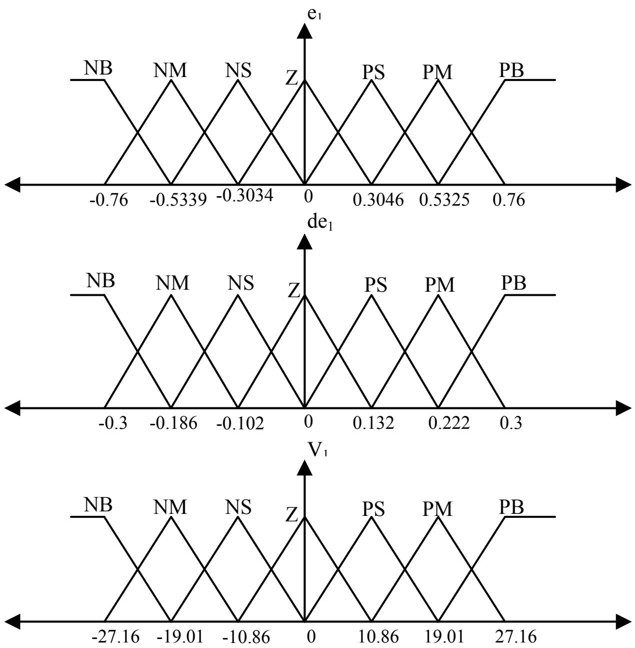

Figure 4. The membership functions of the enthalpy

Suitable ranges are chosen for these variables in the membership functions experimentally. Triangular membership functions are preferred since fast response is necessary for the system.

V. THE PROPOSED FGPI CONTROLLER

In this study, a fuzzy gain scheduling proportional and integral (FGPI), controller is proposed to regulate outputs of power and enthalpy since it is a suitable technique for non-linear and time-variant systems. This technique is used to adjust the gains of the PI controller according to disturbances in the system outputs. Two different FGPI controllers have been applied for power and enthalpy outputs. The inference mechanism for both controllers have seven rules and membership functions. The appropriate rules for Ki and Kp are given in Table 2 and 3, respectively [11]. All rules in the tables are prepared as in FLC. The membership functions of this controller are given in Figure 5 and figure 6.

Table 2. Rules of K_I parameters for power and enthalpy outputs

e \ de	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PB	PB	PM	PM
NM	PM	PM	PM	PM	PM	PS	PS
NS	PS	PS	PS	PS	PS	Z	Z
Z	Z	Z	Z	Z	Z	NS	NS
PS	NS	NS	NS	NS	NS	NM	NM
PM	NM	NM	NM	NM	NM	NM	NB
PB	NB	NB	NB	NB	NB	NB	NB

Table 3. Rules of K_P parameters for power and enthalpy outputs

e \ de	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NB	NM	NM
NM	NM	NM	NM	NM	NM	NS	NS
NS	NS	NS	NS	NS	NS	Z	Z
Z	Z	Z	Z	Z	Z	PS	PS
PS	PS	PS	PS	PS	PS	PM	PM
PM	PM	PM	PM	PM	PM	PM	PB
PB	PB	PB	PB	PB	PB	PB	PB

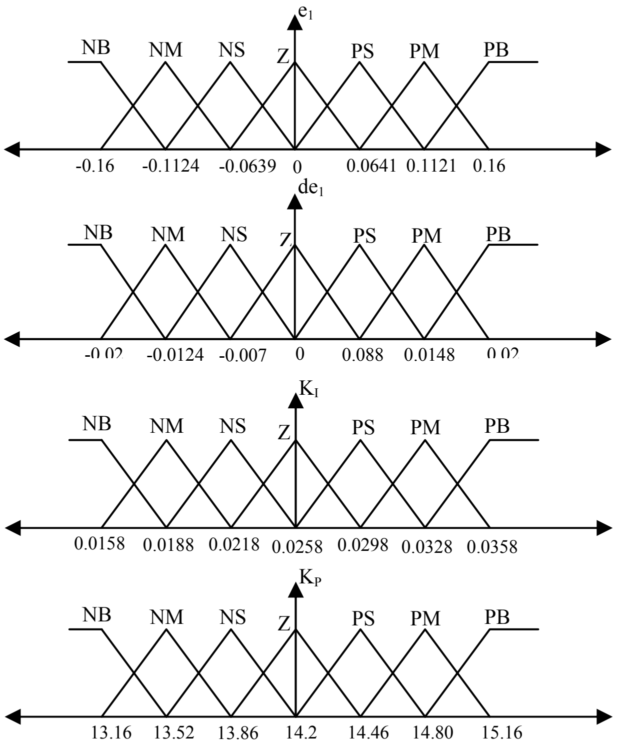

Figure 5. The membership functions of power in FGPI controller

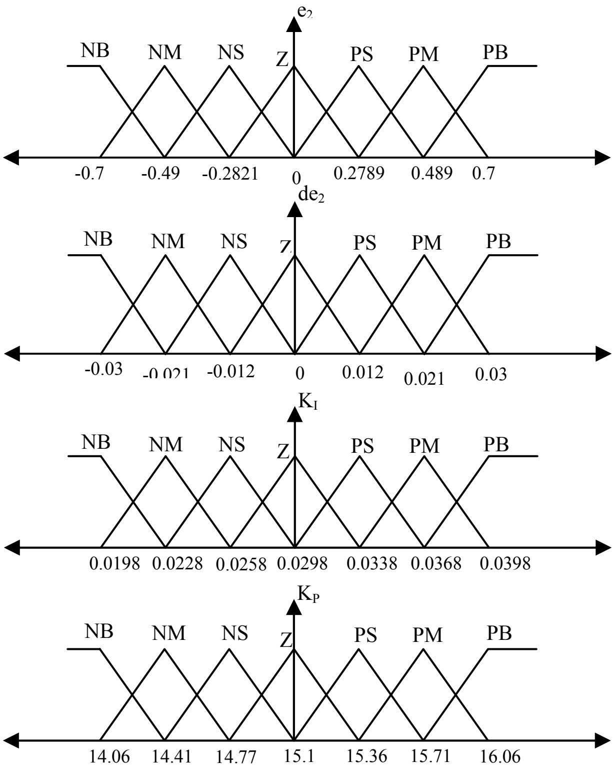

Figure 6. The membership functions of enthalpy in FGPI controller

VI. SIMULATION AND RESULTS

In this study, different control techniques were applied to a 765 MW coal fired thermal power plant. A reduced mathematical model of the power plant was developed by using real time data on CADACS software [Rift]. Matlab 6.5 – Simulink [12] software was used for design of controllers. The same values of the power plant parameters were used in the simulations for a comparison. Simulation in conventional control techniques without a decoupler must not realized for linearized multi inputmulti output systems. Therefore, the decoupler unit is used with the PID controller. It has also been used to provide the same conditions in the FL and FGPI controllers. Power and enthalpy deviations of the system outputs are shown in Figure 7 and figure 8. Settling times and maximum overshoots are showed in Table 4 which indicates that power overshoot of the conventional PID, the FL and the FGPI controllers are 30%, 8% and 2%, respectively whereas enthalpy overshoots with 23% for the PID, 1% for the FL and 2% for the FGPI. These results are shown that the proposed FGPI controller has better performance for the two situaitons. From the table, it can be drawn such a conclusion that FL controller perofrmances are better than the proposed FGPI controllers. However, if the Figures 7 and 8 are examined attentively, it is seen that outputs of the FL controller are not fit range of 10% band. Therefore, the FGPI controller has better performances than the rest of controllers'. As for the settling times of the power output, the FGPI was found 52 seconds while the FL and the PID controllers were found 8 and 190 seconds. For enthalpy outputs, the settling times are 26, 11 and 124 seconds for the FGPI, the FL and the PID controllers respectively. In this situation, since oscillations of the FL controller can not be stopped or reduced, again, the FGPI controller gave good results than the others'. All results for the controllers are given in Table 4 and Figures 7and 8.

Table 4. System performances for conventional the PID, the FL and the FGPI controllers

		PID	FLC	FGPI
Overshoots (%)	Power Output	30	8	2
	Enthalpy Output	23	1	2
Settling Times (sec)	Power Output	190	8	52
	Enthalpy Output	124	11	26

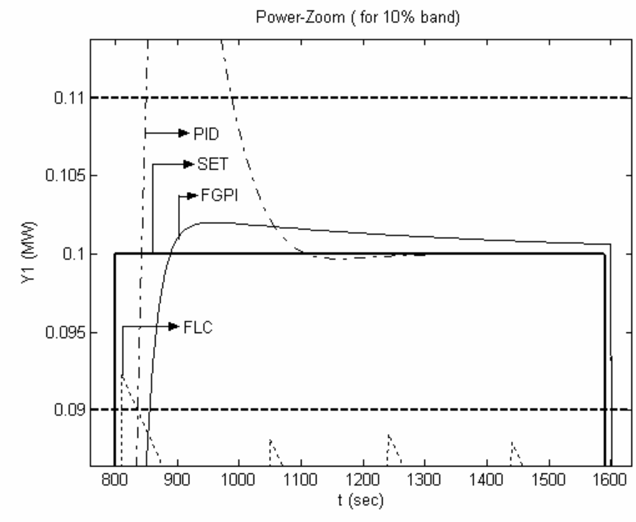

Figure 7. Zoomed view of electrical power output with all controllers

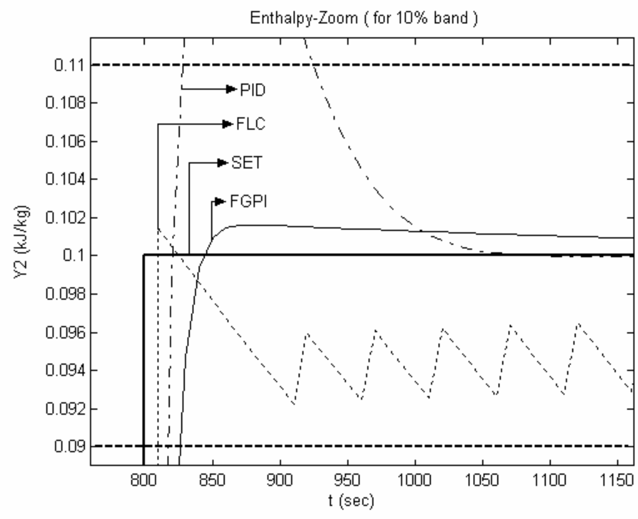

Figure 8. Zoomed view of enthalpy output with all controllers

VII. CONCLUSIONS

In this study, the step response of a conventional PID, a FL and a FGPI controllers has been investigated seperately for a 765 MW coal fired power plant. For this purpose, first, the plant was modeled by use of real time data on CADACS software. Then, the controllers were prepared with Matlab 6.5-Simulink software. A conventional PID, a FL and a FGPI controllers were modeled to control power and enthalpy outputs of the system. As is shown in Table 4 and Figure 7 and figure 8, the proposed FGPI controller has better performance for the settling times and the overshoots of the system outputs. Therefore, the FGPI controller are recommended for controlling outputs of such power plant.

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