An Investigation Of Productivity In Boilers Of Thermal Power Plants With Fuzzy Gain Scheduled PI Controller

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Abstract— Power plants need to be controled because of electricity generation cost and to be reduced corrosion of the equipmet used in them. For these reasons, special care has to be taken for their two outputs, settling time and overshoot, and their productivity. In this study, a fuzzy gain scheduled proportional-integral, FGPI, controller was designed to arrange the power and enthalpy outputs in two boilers with different productivity values of a 765 MW coal-fired thermal power plant. The simulation results show that the first boiler model (Model-1, M1) with 95% productivity has better preformance on the settling time of power and enthalpy outputs. As for the overshoots, the second boiler model (Model-2, M2) with 70% productivity has better performance for the two outputs.

Keywords - **Electrical Energy, Thermal Power Plant, Modelling, Productivity, Fuzzy Gain Scheduled PI Controller (FGPI).**

I. INTRODUCTION

The dynamic behaviour 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]. However, power plants need to be controled because of electricity generation cost and to be reduced corrosion of the equipmet used in them. For these reasons, special care has to be taken for their two outputs, settling time and overshoot, and their productivity. Productivity, especially, is very important parameter among these parameters because of energy conservation in these plants. Also, settling time of the plant is to be reduced by way of increasing the productivity. Therefore, both generation costs cut down and the equipments' lifetime goes up. For these aims, two boiler models, M1 and M2, which have 95% and 70% productivity values respectively, were chosen in this study. Boiler models were accepted clean for comparison.

Power plants have some inputs and outputs. The main input variables of a thermal power plant shown in Figure 1, are fuel flow, feed water, injection water and air. The outputs of the system are electrical power, steam pressure, steam temperature, and combustion gas. Some of the inputs and outputs are more important than the others since these are adequate for modelling the power plant. They are coal feed and feed water flow as the inputs, and the electrical power and steam enthalpy as the outputs [1].

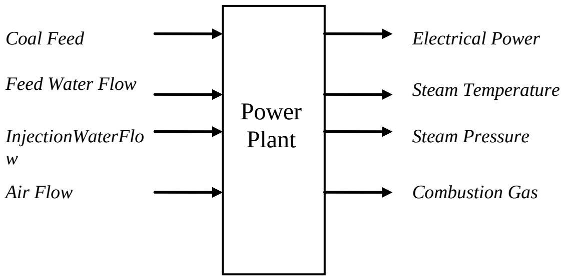

Fig 1. Power plant as a multivariable dynamic system

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 technique 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]. In this paper, a new FGPI controller is tested for controlling outputs of two different 765 MW coal fired power plants. The comparison between these models shows that settling times of the M1 with 95% efficiency are better than that of the M2. This situation shows that the system productivity is very important for controlling the power plants.

II. MODELLING OF 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 vantilators. 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 modelled by a strongly coupled multivariable system. This makes it very interesting from a control engineering point of view. In this study, two different boiler models are chosen for comparison study. These models are clean boilers however their productivities are different from each other. M1 is working with 95% efficiency whereas M2 with 70% efficiency. Therefore, influence of the system productivity will be investigated in this paper.

In the boiler, the chemical energy is converted to thermal energy. The dynamic behavior of a boiler heavily depends on many different opereating 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 [9]. Control diagram of the power plant model is shown in Figure 2. In this figure, two controllers having different structures are used to control the outputs. During simulation process, two different FGPI controllers are applied to the models seperately as controllers. Also, a decoupling unit is used with all controllers to obtain diagonality between the controllers and the power plant.

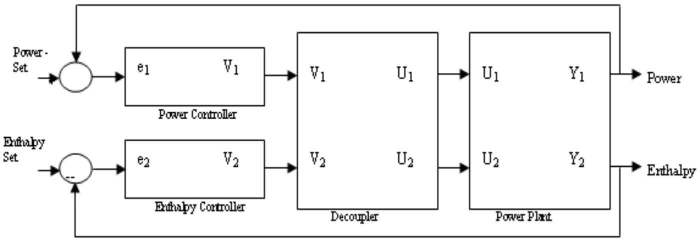

Fig 2. Control diagram of the power plant model

The matrix form of the power plant model is given in Equation (1).

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \tag{1}$$

Y_1, Y_2 are electrical power and enthalpy outputs, respectively. U_1 is the coal feed input, and U_2 is the feed water flow input [10]. It is used a decoupling system to establish a diagonality between inputs and outputs of the system. V_1 and V_2 are inputs of the decoupling unit. The matrix form of the decoupling unit is given in Equation (2).

$$\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \begin{bmatrix} 1 & -G_{12}/G_{11} \\ -G_{21}/G_{22} & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{2}$$

If equation 2 is subsituted into Equation 1, Equation 3 is obtained.

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} G_{11} - \dfrac{G_{12}G_{21}}{G_{22}} & 0 \\ 0 & G_{22} - \dfrac{G_{12}G_{21}}{G_{11}} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{3}$$

In Equation 3, diagonality of input and output relations can be realized easily from the matrix form. Therefore, Y_1 is depend on only the input U_1 and output Y_2 is depend on only the input U_2 [11].

III. FUZZY GAIN SCHEDULED PI CONTROLLER (FGPI)

Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. The use of fuzzy sets provides a basis for a systematic way for the application of uncertain and indefinite models [12]. Fuzzy control is based on a logical system called fuzzy logic. It is much closer in spirit to human thinking and natural language than classical logic systems [13]. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is the power plant control. According to many researchers, there are some reasons for the present popularity of fuzzy logic control. First of all, fuzzy logic can be easily applied for most of applications in industry. Besides, it can deal with intrinsic uncertainities by changing controller parameters. Finally, it is appropriate for rapid applications. Therefore, fuzzy logic has been applied to industrial systems as a controller. Human experts prepare linguistic descriptions as fuzzy rules. These rules are obtained based on experiments of the process' step response, error signal, and its time derivative [13].

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. In this work, the appropriate rules are given in Table 1 and Table 2. The rules which belong to the membership functions are written in the same way for each fuzzy logic controller.

TABLE I

RULES OF K_I PARAMETERS FOR POWER AND ENTHALPY OUTPUTS OF EACH MODELS

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 II

RULES OF K_P PARAMETERS FOR POWER AND ENTHALPY OUTPUTS OF EACH MODELS

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*

Names of the abbreviation in the tables and figures 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 [13]. The ranges of all membership functions are determined through taken into consideration of the critical points for system control.

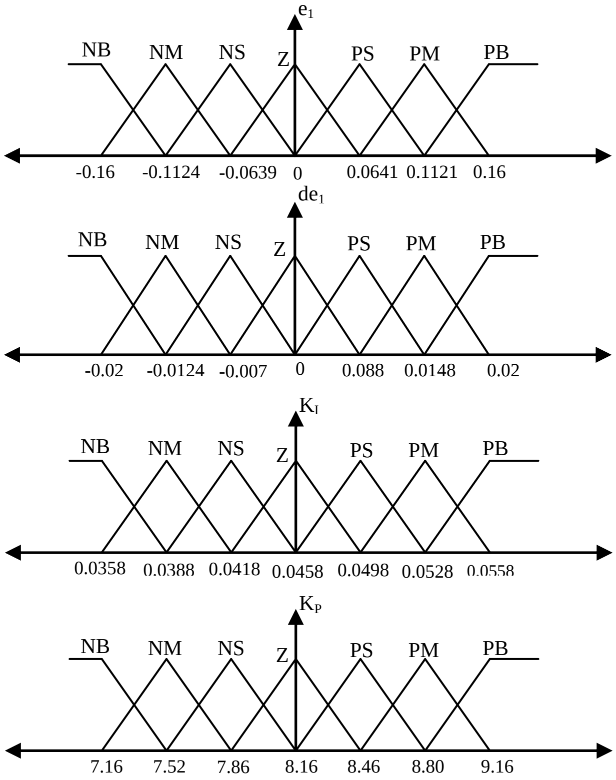

Fig 3. The membership functions of power FGPI controller of M1

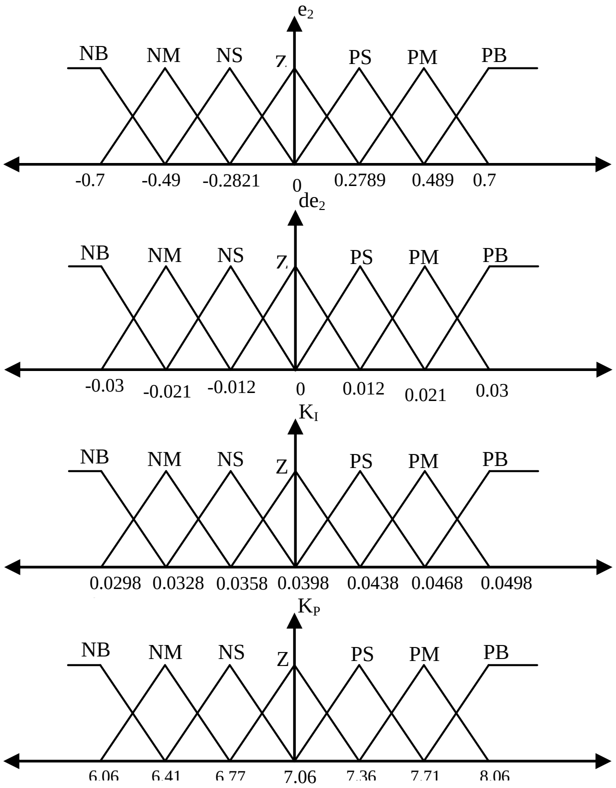

Fig 4. The membership functions of enthalpy FGPI controller of M1

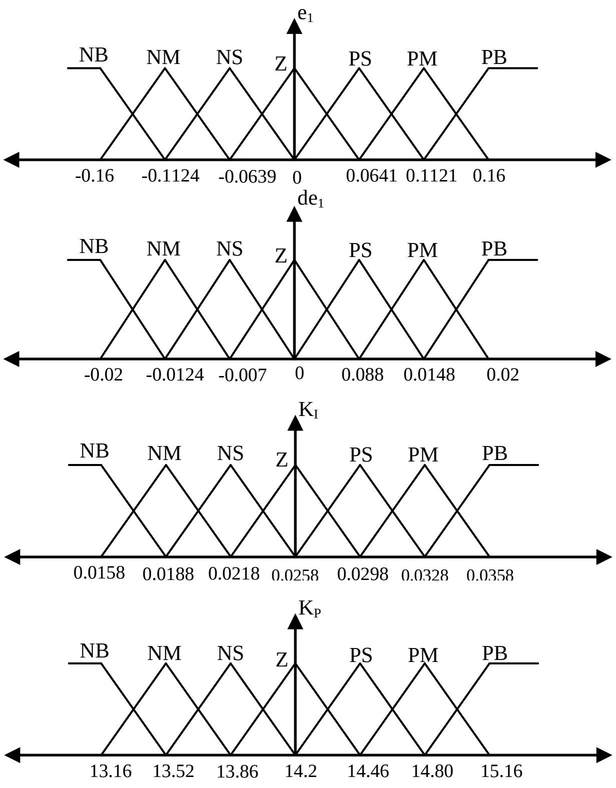

Fig 5. The membership functions of power FGPI controller of M2

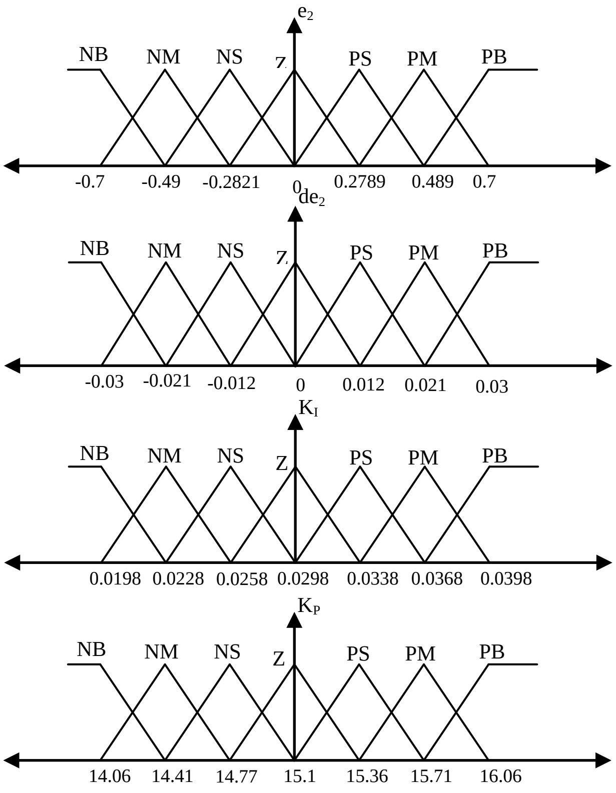

Fig 6. The membership functions of enthalpy FGPI controller of M2

The membership function sets for errors (e_i), derivative errors (de_i) and decoupling unit inputs (V_i) are shown in Figures 3-6. Figures 3-4 belong to the FGPI controller of M1. Figures 5-6 belong to the FGPI controller of M2. 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.

IV. SIMULATION AND RESULTS

In this paper, two different FGPI controllers are applied to two different 765 MW coal fired thermal power plants. Reduced mathematical models of the power plants are developed by using real time data on KEDDC software. Matlab 7.1 – Simulink software[14] is used for designing all the controllers. The different values of the power plant parameters are used for each model. Power and enthalpy deviations of the system outputs are shown in Figures 7-8. Settling times and maximum overshoots are shown in Table 3. It is shown in Table 3 that power overshoots of models are 3% and 2% for M1 and M2, respectively. For the enthalpy overshoots, M2 has again better overshoot value than the other. Its enthalpy overshoot value is 2%. M1 has 4% overshoot value. It is understood that productivity increase is rising the output of overshoot as expected. As for the settling time, settling time of the M1 is 19 seconds, and settling time the M2 is 29 seconds for the power output. For the enthalpy outputs, the settling times are 5 and 26 seconds for M1, and M2, respectively. Therefore, decreasing the settling time, energy conservation is more better maintained on M1 than that of the M2. All these states above mentioned can also be shown in Figures 7-8.

TABLE III
SYSTEM PERFORMANCES FOR THE TWO MODEL WITH FGPI CONTROLLERS

FGPI Controller		M1	M2
Overshoots (%)	Power Output	3	2
	Entalpy Output	4	2
Settling Times (sec)	Power Output	19	29
	Entalpy Output	5	26

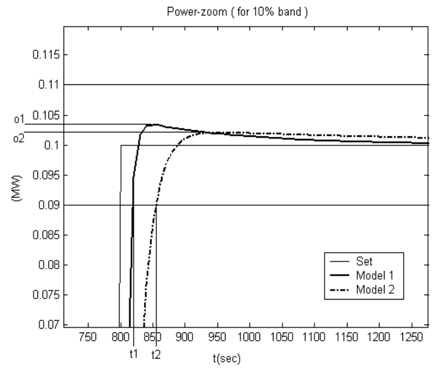

Fig 7. Zoomed power output for the models

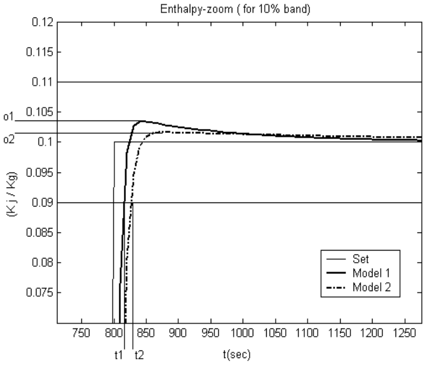

Fig 8. Zoomed enthalpy output for the models

V. CONCLUSIONS

In this paper, two FGPI controllers responses have been investigated for two 765 MW coal fired power plant models. For this reason, firstly, the plants have been modelled by using real time data on KEDDC software. After that, the controllers are designed with Matlab 7.1 – Simulink software. FGPI controllers are modelled to control power and enthalpy outputs of the system. As is shown in Table 3 and Figures 7-8, M1 has high overshoots than that of M2 because of its productivity. As for the settling times, M1 has highly small values for power and enthalpy outputs than that of M2. Therefore, it is shown that the productivity of the boiler in a power plant is one of the important parameter to control power and enthalpy of the system and to conserve the exhausted energy in power plants. In addition, advanced control techniques can be recommended to control outputs of such power plants.

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