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# Fuzzy Model-based Predictive Control in Controlling Temperature of Boiler of Thermal Power Plant

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**ABSTRACT:** In thermal power plant, boiler is an important device. The boiler control system is very complicated with a lot of parameters which need to be monitored and controlled. Air temperature control plays an important role in improving the quality of the boiler control system. This paper presents an approach of using the fuzzy logic for identification of control objects, then the predictive control method is applied to control temperature of the boiler in thermal power plants.

**KEYWORDS:** MIMO, MPC, FIS, GAs.

## I. INTRODUCTION

Pha Lai 2 is one of the biggest thermal power plant in Vietnam which has modern design with 2 groups of generators, each has capacity of 300 MW. It has been built to meet international standards on environment protection. It is designed with the latest monitor and control system that is Yokogawa distributed control system (DCS). Turbine control system MARK V is manufacturing and assembled by General Electric of the USA.

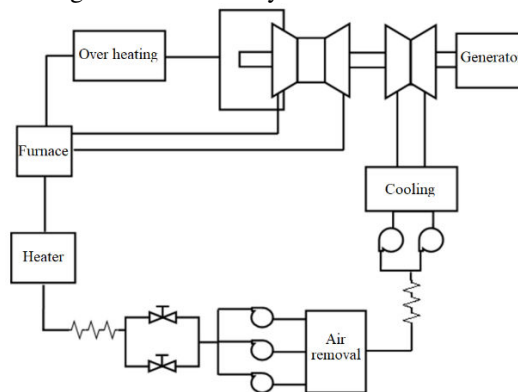


Fig. 1. Flow diagram of Pha Lai 2 thermal power plant

The thermal cycle in a thermal power plant is a closed cycle of steam and water.

## II. BUILDING THE BOILER FUZZY MODEL

The boiler of the Pha Lai 2 is single drum type, natural circulation, dry slag waste combustion chamber, balanced ventilation, 1-stage intermediate superheat and subcritical pressure, so it is suitable for working out-door. The boiler is designed to burn powdered coal with a direct coal injection system.

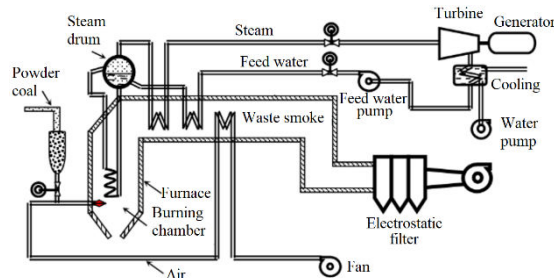


Fig. 2. The boiler BZK-220-100-10C

Input-Output (IO) data acquisition

Input (u <sub>k</sub> )	Output (y <sub>k</sub> )	Input (u <sub>k</sub> )	Output (y <sub>k</sub> )
6.458	4.7661	3.413	4.4789
6.454	4.7637	3.451	4.5085
6.372	4.8394	3.442	4.5176
6.319	5.003	3.393	4.5094
6.471	5.0176	3.419	4.5101
...	...	...	...
4.387	5.3619	3.215	4.5585
...	...	...	...

The set of input-output data is practically measured at the plant. The number of collected patents is 3000. The sample time is T<sub>s</sub> = 2 s.

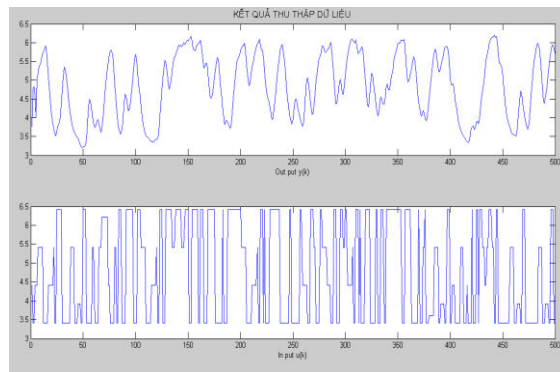


Fig. 3. The result of data acquisition

The predictive model of the boiler is a fuzzy model with a recurrent vector input chosen from the IO data set of the control object in the past.

$$\hat{y}(t | \theta) = f(\varphi(t), \theta)$$

$$\varphi(t) = [y(t-1), K, y(t-Ny), u(t-1), K, u(t-Nu)]$$

Where:  $\varphi(t)$  is recurrent vector.

$\theta$  is parameter vector of the fuzzy model.

In order to obtain the predictive fuzzy model of the control object, it is necessary to:

- Define the appropriate recurrent elements from the IO data set in the past ( $\varphi$ ).
- Define structure of the fuzzy model.
- Define the suitable parameters for the fuzzy model.

According to experience, the appropriate recurrent elements are selected in the following set of 10 past elements:

$$\{y(t-1), y(t-2), y(t-3), y(t-4), u(t-1), u(t-2), u(t-3), u(t-4), u(t-5), u(t-6)\}$$

The selection is done by sequential tree search in Matlab. The selected recurrent vector is  $[y(k-1) y(k-2) u(k-3)]$

The result of control object identification is shown in Fig. 4.

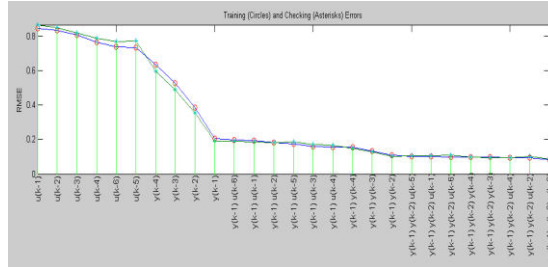


Fig. 4. Control object identification

Tagaki-Sugeno model is selected for the fuzzy model. The result is shown in Fig. 5.

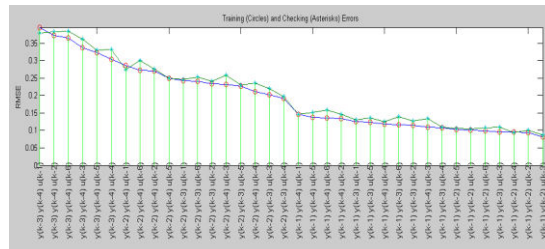


Fig. 5. The result of defining fuzzy model structure

The training for determining the parameters of the predictive fuzzy model is implemented by:

- The method of least squares: to adjust the parameters of the linear function that determines the output by combining the inputs  $(\theta^l x_1^i + K + \theta_p^l x_p^i + \theta^l)$
- The method of movement against the gradient direction: to adjust the position of the input membership functions

The training result is shown in Fig. 6.

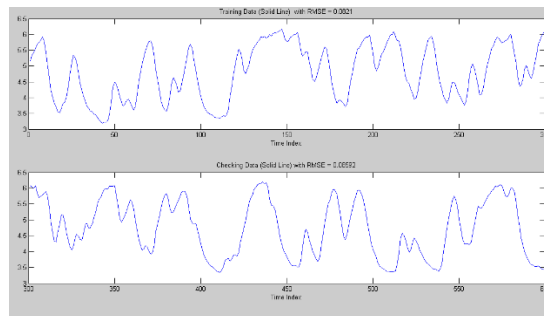


Fig. 6. Training result and model verification

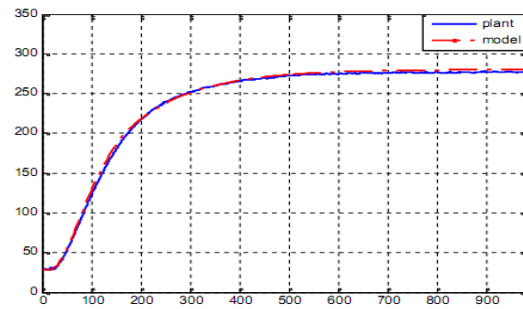


Fig. 7. Dynamic characteristic of system

Remark: Identification results show that the control object is exactly described by the fuzzy model.



### III. PREDICTIVE CONTROLLER DESIGN FOR CONTROLLING THE BOILER TEMPERATURE

To design the predictive controller for controlling temperature based on the solution of optimal control by Genetic Algorithm method, Matlab sub-functions are built:

- **Population Initialization:**

**generation=genbin(num\_chro, num\_bit);**

generation: is initiated population.

num\_chro: number of chromosomes.

num\_bit: number of coding bits for each chromosome.

- **Decoding Chromosomes**

To calculate predictive level of each chromosome, chromosome need to be decoded:

**Val=bin2real(chro, range);**

chro: chromosome need to be decoded

range: values of real signal.

- **Regeneration**

The regeneration function calculates predictive level of chromosomes, regenerates thereby the appropriate chromosomes and create a new population.

**Newgen=selectmin(gen,myfis,lamda,TDLy,TDLu,range\_dul,Hp,ref,y,u,t)**

gen: is the population before being regenerated

myfis: is the predictive model of the control object.

lamda: is the weight of the objective function

TDLy,TDLu: is the delay line y, u.

range\_dul: is range of the input signal change.

Hp: predictive range

ref: reference

y,u: the output signal, input signal

t: time

newgen: regenerated population.

- **Hybrid**

Hybridization is performed by the following sub-function:

**newgen=mate(gen,ma,n\_point)**

gen: Population before hybridization

ma: is the probability of hybridization

n\_point: is the number of hybrid points

newgen: is new population after hybridization

- **Mutation**

The mutation is performed by the following subfunction:

**newgen=mutae(gen,mu)**

gen: Population before mutation

mu: is the mutation probability

newgen: is the new population after mutation.

- **GA controller**

The GA controller is built by the following function:

**u=mpc\_GA(myfis, lamda, TDLy, TDLu, model, Ts, Hp, num\_bit, num\_chro, num\_gen, Amp, K\_fb, Tmax);**

where:

model: is the object to control

T<sub>s</sub>: is the sampling period.

Num\_gen: is the number of evolutionary generations.

Amp: reference signal amplitude

K\_fb: feedback gain.

Tmax: simulation time.





IV. SIMULATION AND VERIFICATION

- The effect of weight  $\lambda$  on the output quality:

$H_p=5, H_c=1, \lambda=0.001, num\_bit =15$

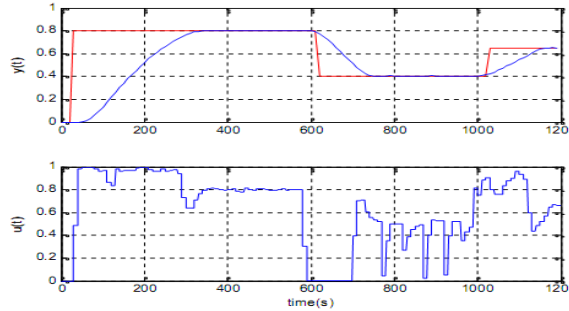


Fig. 8. System response with  $\lambda=0.001$

$H_p=5, H_c=1, \lambda=0.1, num\_bit =15$

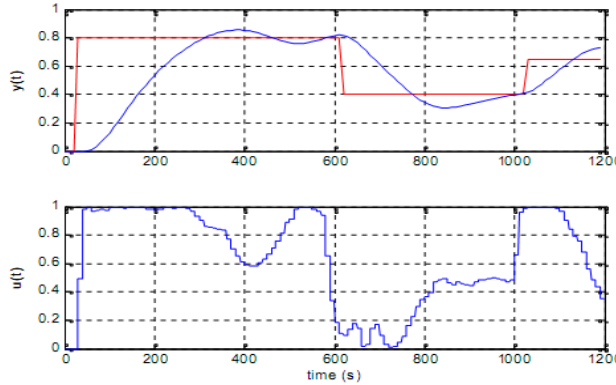


Fig. 9. System response with  $\lambda=0.1$

When increasing  $g$ , the control signal is smoother, but the response of the system becomes worse. Thus, the weight  $\lambda$  has a large influence on the quality of the system. It must be chosen experimentally depending on specific problem: small  $\lambda$  decreases the tracking error, large  $\lambda$  is selected when energy optimization is necessary.

- The effect of number of chromosome coding bits

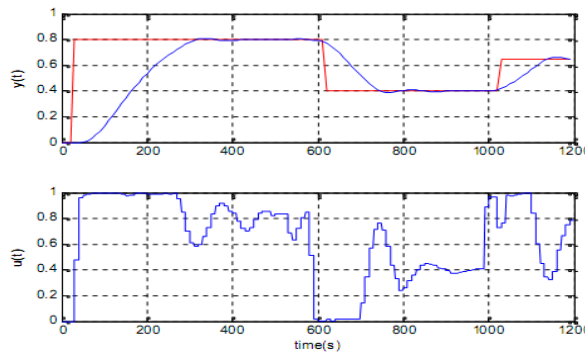
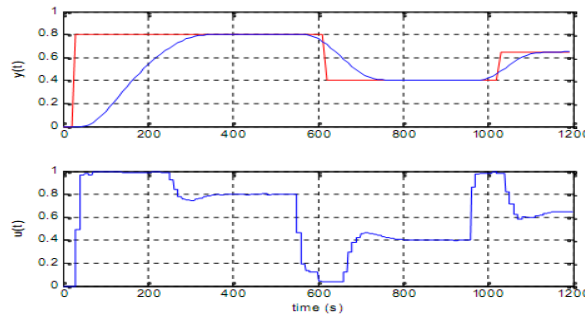


Fig. 10. System response with  $num\_bit =10$

When reducing the number of chromosome coding bits, it means reducing the accuracy of the solution, but calculation time is reduced.

- The effect of output predictive range  $H_p$

In cases where a higher quality of control is required and allows for an increase in the computation time, we can increase the control domain, the prediction domain, the number of chromosomes in the population, and the number of generations

Fig. 11. System response with  $H_p=8$ .

When reducing the number of bits to encode the chromosome, it means reducing the accuracy of the solution, but in return, the time of each calculation step can be reduced.

## V. CONCLUSION

The GAs method can relatively well solve the MPC optimization problem. However, in this method, the number of parameters to be regulated is relatively large. The time for each step is relatively large. The fuzzy model-based predictive controller is applied to control the boiler temperature, giving good results, the predictive characteristic curve is relatively close to the control curve. This makes the transient shorter, the overshoot of the transient characteristic smaller. The adjustment of parameters in fuzzy controller is simpler than conventional methods.

## ACKNOWLEDGEMENTS

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