

Model based design of a fuzzy temperature control for a steam generator

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1. ABSTRACT

The paper describes the design of a fuzzy temperature control for a Benson type steam generator in a coal fired 350 MW power plant of *Neckarwerke* public utility company. The design is based on a model which has been created using the ACSL version of Modular Modeling System (MMS).

The fuzzy algorithm is compared to a conventional PI-control system. The most significant advantage of the fuzzy controller is its low sensitivity to plant parameter variations. The behaviour of the fuzzy system is quite satisfactory over the full range of operation, i.e. from 35% to 100% load without any changes to the algorithm, whereas the conventional PI-controller would require parameter adjustment.

2. INTRODUCTION

Large steam generators in power plants require efficient temperature control over a wide range of operation. A proper control system design requires, however, a good understanding of the boiler dynamics. This, because of the great complexity involved, calls for reliable system models.

Influenced by the needs of nuclear power industry to study emergency situations powerful tools for simulating transients in thermo hydraulic systems have been developed. These tools are nowadays available for fossil fired power plants too.

Temperature control is primarily based on the ratio of feedwater to heat flow (fuel flow). Using, however, only feedwater e.g. as control variable results in poor control behaviour. The steam generator supplier has, therefore additionally, provided four coolers for mixing spray water with superheated steam.

3. STEAM GENERATOR MODEL

The ACSL version of the Modular Modeling System (MMS) code has been used to create a model, representing the dynamic system behaviour over the full range of operation from start up to shut down. The model contains the high pressure and the reheater sections of the steam generator, represented by a number of lumped parameter models of the major components like preheater, evaporator including burners, superheater, reheater sections, connecting pipes, valves etc. The module characteristics are derived from first principles like mass, energy, and momentum conservation.

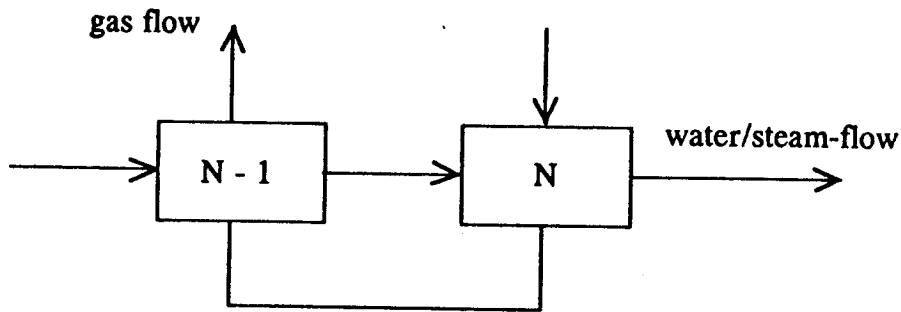


Figure 1. Nodal representation of thermohydraulic systems .

The steam generator is thus represented by interconnected nodes (Figure 1.), where the node equations for node N may be written (see e.g.[1]) as

$$\dot{m}_N = \dot{m}_{Ni} - \dot{m}_{No} \quad (1)$$

$$\dot{U}_N = (\dot{m}h)_{Ni} - (\dot{m}h)_{No} + \dot{Q}_N \quad (2)$$

$$\dot{m}_{Ni} = K \left[\rho_{No} (p_{No} - p_{Ni}) \right]^{1/2} \quad (3)$$

where:

- \dot{m} = massflow or rate of change of mass in volume N
- \dot{U} = rate of change of internal energy
- h = specific enthalpy
- p = pressure
- \dot{Q} = heat transfer rate between steam / water and gas
- ρ = density
- indices i, o for inlet and outlet, respectively.

Equations (1), (2), (3) represent mass balance, energy balance and a simplified steady-state momentum balance (extended versions of the momentum balance being available in MMS, [2]).

In combination with the thermodynamic water/steam and gas property functions and heat transfer relationships, equ.(1) to (3) provide a set of solvable equations.

The MMS representation of the steam generator is shown in Figure 2. .

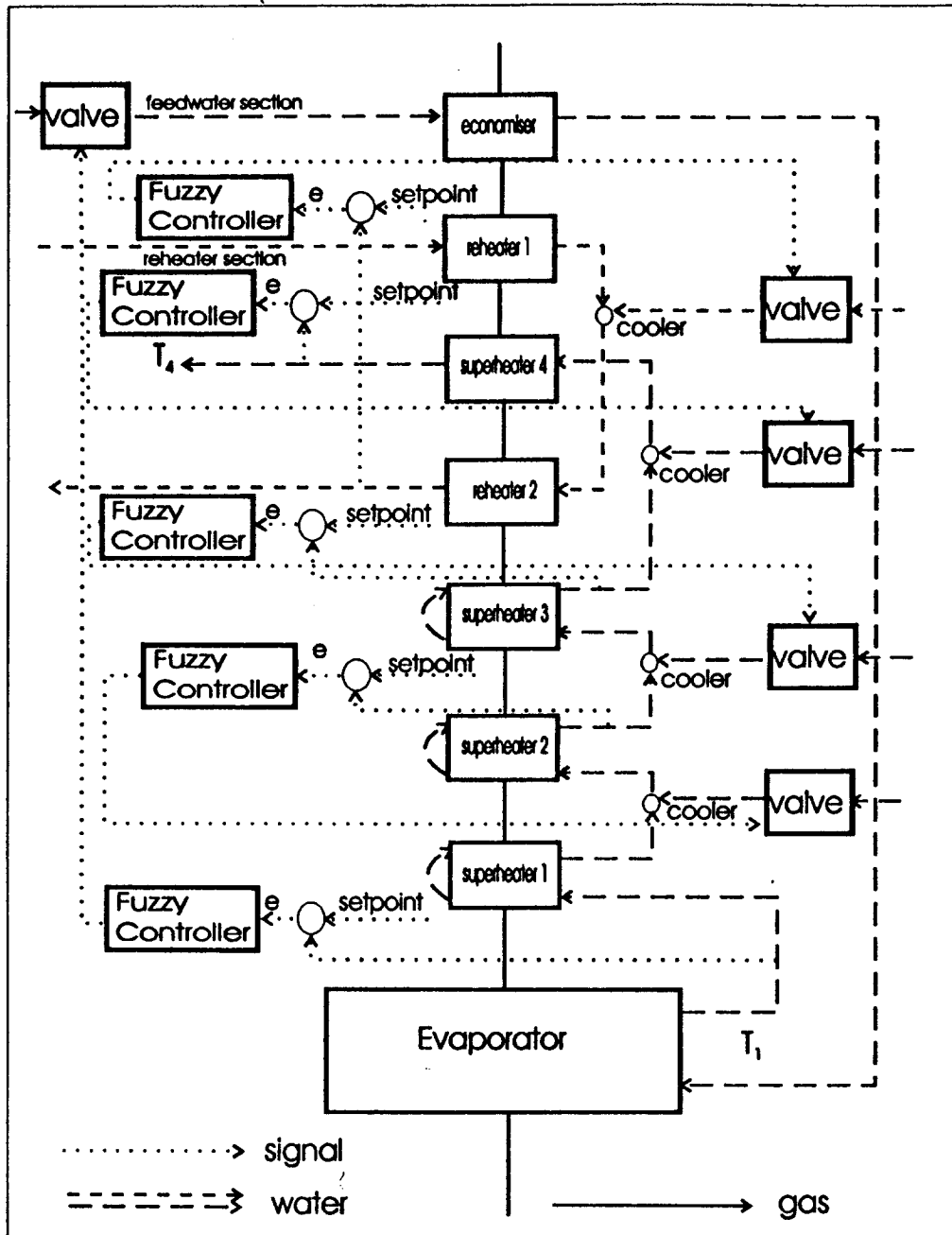


Figure 2. Model of steam generator with control modules

4. CONTROL DESIGN

The fuzzy algorithm thus uses five control variables to act on the steam generator temperature profile. These control variables being feedwater flow, three spray water flows in the high pressure section and one spray water flow in the reheater section as shown also in Figure 2.

Input variables of the fuzzy controller are temperature error E (difference between setpoint and plant output) and the rate of change of error δE . Input for the PI-Controller is only E . Total controller output is the sum of Fuzzy- and PI-Controller output. The output governs the spray water valve.

The fuzzy controller has a hybrid structure (Figure 3).

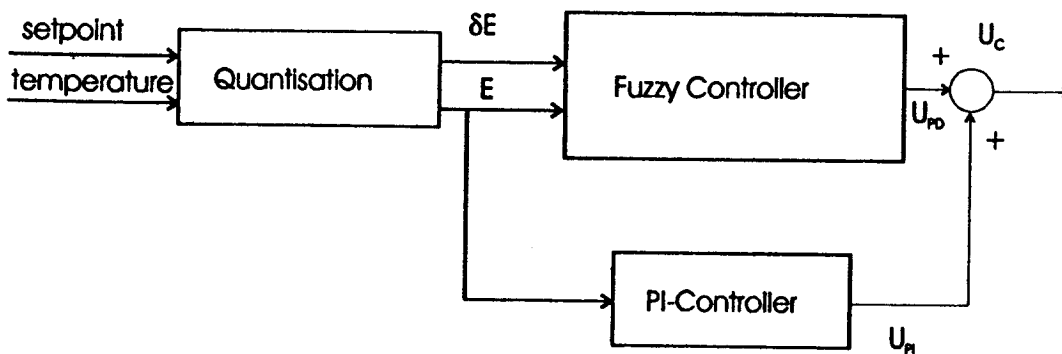


Figure 3. Fuzzy PD + PI

The fuzzyPD/PI-controller produces the following output:

$$U_C = U_{PD} + U_{PI} \quad (4)$$

with $U_{PI} = K_1 * E + K_2 * \delta E$

The Fuzzy Controller is working with the following parameters:

-The input variables are fuzzified with three linguistic variables (Figure 4).

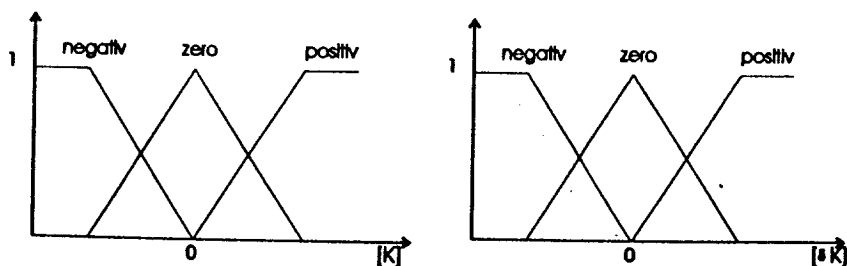


Figure 4. Membership functions of error and δ error

-The rule table consists of nine rules as shown below

Table 1
Rule Table

error error	negative	zero	positive
negative	low	low	normal
zero	low	normal	full
positive	normal	full	full

-For defuzzification also three linguistic variables are used and the defuzzification method is Centre of Maximum (CoM) Figure 5.

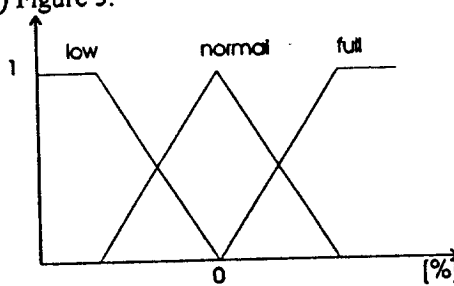


Figure 5. Membership function: opening of valve

To show the differences to conventional control methods the five FuzzyPD/PI-Controllers are replaced in a second calculating by optimised PI-Controllers.

5. RESULTS

To test the controller outline the response of a change of fuel flow is calculated. This is done at 35% and 100% load. The following figures (6-9) show the temperature errors at evaporator exit (ERRORT1) and superheat exit(ERRORT4).

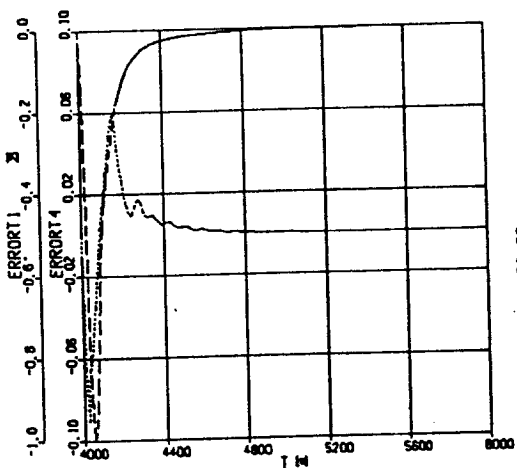


Figure 6. FuzzyPD/PI, 100% load

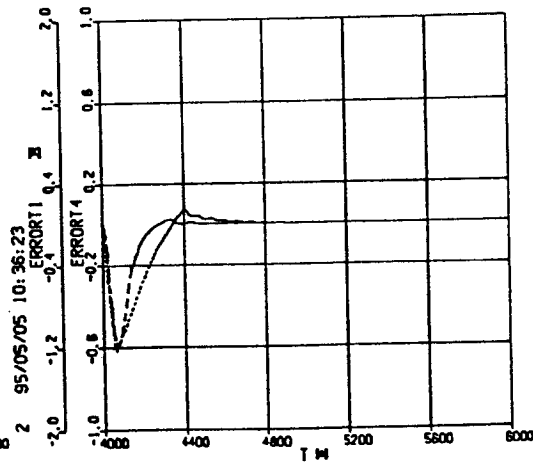


Figure 7. FuzzyPD/PI 35% load

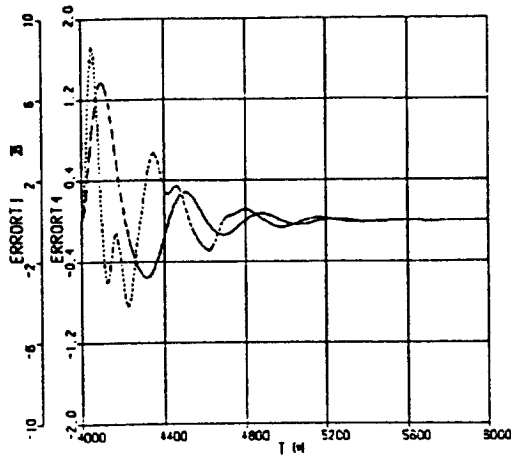


Figure 8. PI 100% load

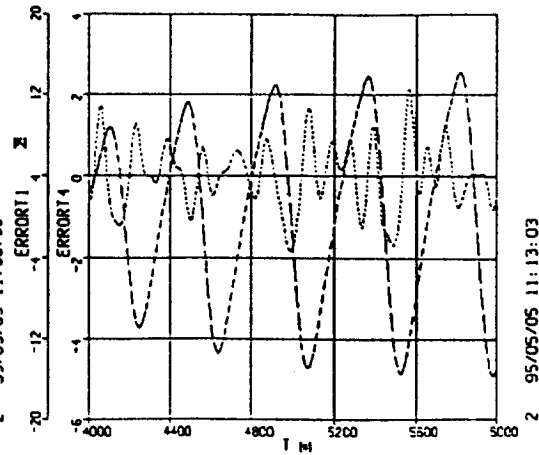


Figure 9. PI 35 % load

Table 2

Summed absolute errors of tests

	FuzzyPD/PI		PI	
	ERRORT1	ERRORT4	ERRORT1	ERRORT4
100 %	99,93	22,37	391,96	1518,0
35 %	110,47	131,73	15731,0	1276,7

The calculations show that peak of errors and the absolute summed error are substantially smaller by using the FuzzyPD/PI controller. In addition the FuzzyPD/PI is more robust against parameter variation. The PI controller becomes instable at 35% load.

6. CONCLUSION

Knowledge-based methods, as fuzzy logic, combined with conventional control techniques gives a new chance to improve control processes. Especially over the full range of operation the fuzzy controller is more robust. A conventional PI controller would require adjustment of controller parameters.

REFERENCES

1. R. Herbrink, Energie- und Wärmetechnik, Teubner-Verlag, Stuttgart 1993.
2. B&W Nuclear Service Company, Modular Modeling System, Release 4, 1994
3. C. J. Harris, C. G. Moore & M. Brown, Intelligent Control Aspects of Fuzzy Logic and Neural Nets, World Scientific, 1993