SUPERHEATER TEMPERATURE CONTROL USING FUZZY ALGORITHM

GA Pereira, VK Prabhulla Chandran, Uma Krishnan
Electronics Research And Development Centre,
Vellayambalam, Thiruvananthapuram, India.

Abstract -

This paper presents the development of fuzzy algorithm for Boiler Superheater Temperature control. Superheater exhibits large amount of transportation lag making all conventional control methods inadequate. The fuzzy algorithm has been successfully developed for real time implementation and tested by simulation using a process model on an IBM PC. Simulation results shows that the controller can be applied to processes with transportation lag and non-linearity, which were usually not controlled very well with a conventional controller. Simplicity and robustness of fuzzy control algorithm makes it superior to other methods.

1. Introduction

Superheater outlet steam temperature is difficult to control accurately due to the non-linear time varying behaviour of the system. Process modelling difficulties and lack of suitable measurements of plant dynamics make most of the conventional control techniques unsuitable and manual control imperative. By manual control, the overall process objectives such as quality and quantity of superheated steam produced is left in the hands of a human operator.

At present some of the thermal power plants employ prediction control technique using plant models. This calls for costly process control packages which need huge computing power for super heater temperature control. They are based on parameter estimation methods and are approximations to real process. Some of these applications in thermal power plant have been reported successful, but difficulties have been experienced when the process operates over wide range of conditions and suffer from stochastic disturbances.

Considering these difficulties process engineers realized that incorporating human intelligence into the controller would be a simple and efficient solution and this led to the development of fuzzy logic controllers. Usually digital computers use binary logic, the values Ø or 1,True or False. It cannot easily represent real world continuous events. Fuzzy logic represents real world events as a continuous spectrum of values with the help of fuzzy sets. Unlike boolean sets whose elements are either in the set or not, fuzzy logic elements have partial membership. So rather than rigidly classifying set membership as true or false fuzzy logic defines it as a continuous time phenomenon. Since they can represent phenomenon continuously fuzzy logic systems operate smoothly giving them a human like quality. The speed of the number crunching machine and the efficiency of the human operator forms the fuzzy controller. Fuzzy logic controllers provide robust control in spite of measurement inaccuracies. This feature provides a reasonable tolerance for prediction inaccuracies in dead time processes. In this approach a fuzzy controller is supplemented with a simple prediction algorithm to compensate for the inherent transportation lag (dead time) of the superheater.

2. Controller Concept

When a human operator controls a process he interprets the process conditions in vague linguistic terms. He infers the magnitude of measurement as small, medium and large or very slow, slow and fast. To represent such inexact information, a non mathematical approach called fuzzy set theory was developed by Zadeh[1].

A fuzzy set is defined with the help of membership function. The membership of an element 'X' in the set A is $u_A(x)$ which is in the range Ø to 1. If $u_A(x)$ is '1' then X is an element of the set A and if $u_A(x) = Ø$, then it is not. If we consider a fuzzy set A with elements a,b,c,d having membership functions of Ø.2,Ø.3,Ø.8 and 1, then by the preceding concept, the elements with a membership function of 1 is a full member of A and others are only partial members. The membership function determines the weightage of each element in the set.

In the above example 'a' has the least weightage and 'd' has the maximum weightage. In a fuzzy controller the control action is dominated by the elements of the set with maximum memberships.

If the control action is to be based on more than one set namely the sets of error and the rate of change of error, then a combination logic is necessary to determine the controller output. To realize this fuzzy logic concept was adapted.

For e.g. If the error is small positive (slightly lower than the desired value) and rate of change of error is medium negative (error is decreasing moderately) then control action shall be small negative (reduced slightly).

2.1 Fuzzy rule

The form of decision rule employed depends on the process under control and the heuristics employed. In this case a single input - single output regulation task is the subject of implementation. The controller is assumed to respond to the system error (e) and its rate of change of error ($\dot{e}$). The position of the final control element is based on a set of linguistic decision rules relating e and $\dot{e}$. The control action is thus represented by a linguistic table called fuzzy truth table(Table I).

For e.g. A typical rule for the Superheater temperature control task could be : If the temperature is slightly(small) low and the temperature is decreasing moderately (medium) then decrease the cooling (attemperator spray control). Here small and medium are imprecise magnitudes for temperature and its rate of change, whereas 'decrease a little' is an imprecisely (coarse) quantified value for the corrective action. The theory of fuzzy sets(membership function) developed by Prof. Zadeh can be used to convert these linguistic statements into precise control action directly.

2.2 Membership function

The entire range of error and rate of change of error are divided in seven classes. They are Large negative(LN), Medium negative(MN), Small negative(SN), Zero(ZE), Small positive(SP),Medium positive(MP) and Large positive(LP) respectively. They are represented using the membership function shown in fig [1].

Here an error of 40% is classified as 0.4 SP and 0.6 MP and a rate of change of error of 15% is taken as 0.4 ZE and 0.6 SP.

The quality of control rules used is dependent on the shape of the fuzzy linguistic functions and the overlapping of subsets. Since there is no clear guidance in fuzzy set theory for the determination of the best shapes for fuzzy sets and on the overlapping of subsets, a triangular membership function is selected for easy implementation. However, an optimum response of the controller can be achieved by trying out various shapes and overlaps for fuzzy sets (this is verified by simulation tests carried out during program development).

2.3 Fuzzy logic

Fuzzy logic operators namely OR AND & NOT are defined as follows[2]

1. The union of two sets, A U B, corresponds to the OR function and is defined by $u(A \text{ OR } B) = \max(u_A(x), u_B(x))$
2. The intersection of two sets, $A \cap B$, corresponds to the AND function and is defined by $u(A \text{ AND } B)=\min(u_A(x),u_B(x))$
3. The complement of a set A corresponds to the NOT function and is defined by $u(\text{NOT } A) = 1 - u_A(X)$.

2.4 Prediction technique

The scheme for implementation is represented in fig [2]. The steam generated is passed through several superheaters to obtain the desired superheater outlet temperature. Fuzzy controller is used to control the final superheater outlet temperature by controlling the attemperator water spray.

Since superheater exhibits large transportation lag, the control action should be applied an adequate amount of time (equivalent to lag) earlier. Therefore, future value of the measured variable (superheater outlet temperature) after transportation lag of 8 secs (typical) is estimated by interpolating the straight line joining the present and the previous values of the measured variable.

$$X(t + 8) = X(t) + 8\,[X(t) - X(t-1)] = 9\,X(t) - 8\,X(t-1)$$

where X(t) , X(t-1) represents present and previous values

Here transportation lag is a load dependent variable, prediction time is to be varied accordingly. This is not detailed in this paper.

2.5 Realisation of Control Strategy

The plant is simulated as a first order system with unity gain, time constant of 10 secs and dead time of 8 secs. Sampling time was taken as 1 sec. The transfer function of the plant model is

$$\frac{C(s)}{R(s)} = \frac{e^{-8s}}{1+10s}$$

which is represented in Z transform as

$$\frac{C(z)}{R(z)} = \frac{0.09z^{-8}}{1-0.9z^{-1}}$$

This is implemented in discrete form as an auto regressive moving average model given by the following equation.

$$C(t) = 0.09\ R(t-8) + 0.9\ C(t-1)$$

The control strategy is as shown in fig (3).

The fuzzy controller is tuned by varying the mid point of the membership functions. Typical values of SP, MP and LP were taken to be 10, 20, 40 respectively. The waveforms observed for a tuned PID and the fuzzy controller were compared and is presented in fig (4).

It can be observed that the fuzzy controller gives a much better response with a simple forward prediction algorithm.

3. Conclusion

The Fuzzy controller algorithm developed for Superheater uses linguistically expressed heuristic decision rules or 'rules of thumb' directly. The aim of the heuristic rules is to obtain a non-linear relationship between system states and control action which gives superior control than a linear one. The control algorithm is tested on an approximate first order process model with dead time and the results indicate superior controllability over conventional controllers and it was less sensitive to noise and parameter changes. The process response obtained testifies that dead time processes can be controlled effectively using heuristic rules based on fuzzy statements.

The authors suggest this as an alternative for those situations where conventional methods fail. Perhaps it is one of the most cost effective and simple to implement solutions to most of the control situations where available sources of information are inaccurate, subjectively interpreted and uncertain. This paper recommends the use of fuzzy controllers in thermal power plant superheater temperature control for improved efficiency of steam generation.

References

1. L.A Zadeh, 1965, "Fuzzy sets," Inform. Contr.,vol 8, pp 338 - 353.

2. Y.F Li and C.C.Lau,1989,"Development of Fuzzy Algorithms Servo Systems, IEEE Control Systems,pp 65 -71.

3. M.M Gupta,T.Yamakawa,(1988),"Fuzzy logic in knowledge based systems,Decision and Control".

4. A.Kaufmann,M.M Gupta,(1988),"Fuzzy mathematical models in engineering and Management science".

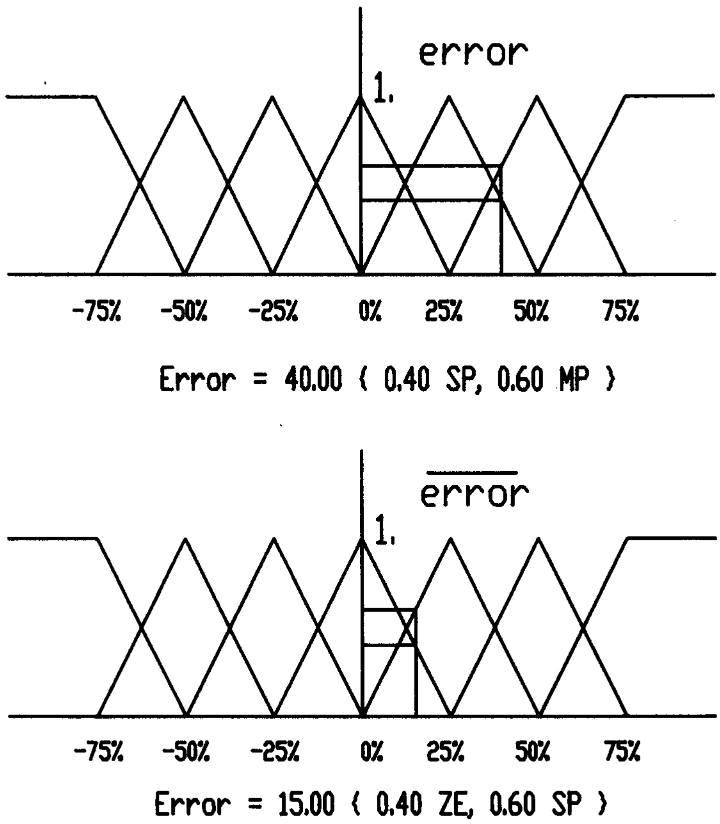

Fig. 1. Membership functions

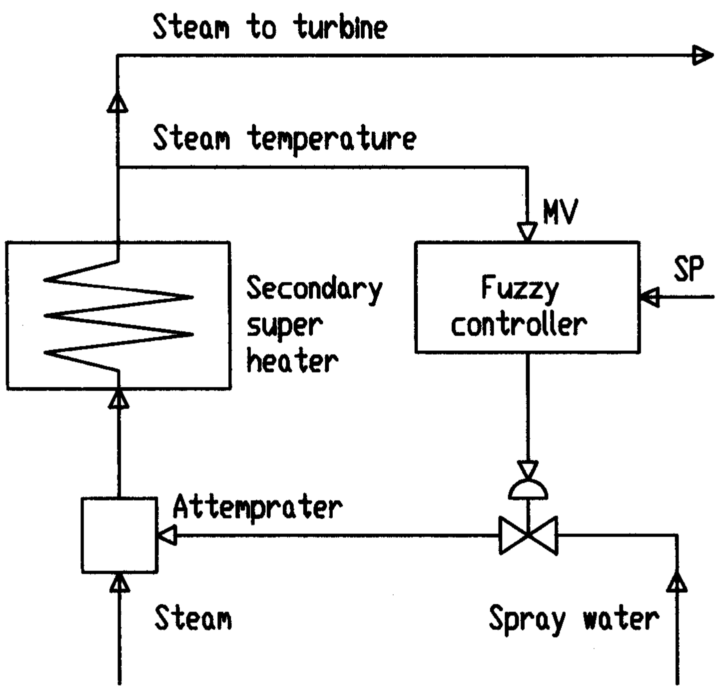

Fig. 2. Basic implementation scheme.

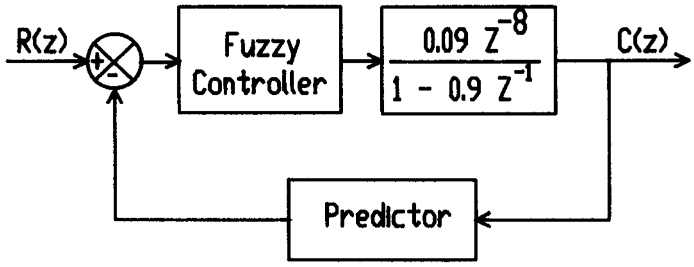

Fig. 3. Control strategy realization.

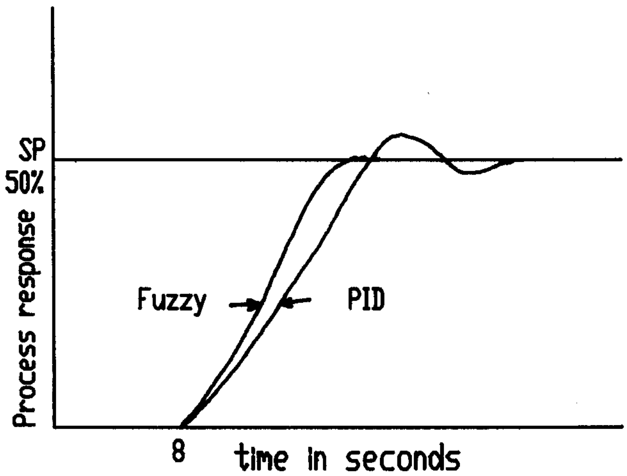

Fig. 4. Process response

e \ $\bar{e}$	LN	MN	SN	ZE	SP	MP	LP
LN	LN	LN	LN	LN	MN	SN	ZE
MN	LN	LN	LN	MN	SN	ZE	SP
SN	LN	LN	MN	SN	ZE	SP	MP
ZE	LN	MN	SN	ZE	SP	MP	LP
SP	MN	SN	ZE	SP	MP	LP	LP
MP	SN	ZE	SP	MP	LP	LP	LP
LP	ZE	SP	MP	LP	LP	LP	LP

Table. 1. Fuzzy truth table