APPLICATION OF A NOVEL FUZZY LOGIC CONTROLLER

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Abstract— *Today's need becomes compulsion to make the invention in the various control system due to the continuous and regular changing in technology and industrial processes. Control system requires fast and flexible responses. The its design need to provide easy and handy practical solution so that it accomplishes the performance requirement. From last few decades, we see emerging and innovative techniques of intelligent control are in the development stage and also developed. One of the areas of soft computing is Fuzzy logic (FL). FL is a intelligent control ability. Its knowledge based operational rules is useful for implementation with ease to control a complex system. In this article, a simple fuzzy controller structure is proposed. Generally we require information on the derivation of the controlled system output variable. But proposed system does not require. Getting the data of output derivation is not so easy and it's cost more. In this paper a fuzzy logic controller (FLC) is developed using the pressure deviation and integral of pressure deviation of a Heat Recovery Steam Generator (HRSG). This proposed FLC can be utilized for pressure controller to regulate the exhaust gas. In turn it gives the input to the HRSG depending upon the requirement of the steam accordingly. The performance of proposed FLC is studied by simulation. The results are taken to do the comparison with the conventional proportional integral (PI) controller system.*

***Index Terms— fuzzy logic controller (FLC),* Heat recovery steam generator *(HRSG),* PI controller, Pressure controller, Simulation study.**

I INTRODUCTION

A control system design should be simple and should give the desired performance. One of the requirements of a control system is the flexibility, it should be able to adapt to a new process with little modifications. FL is one such technique, which can be designed and implemented easily. It can also be modified easily. FLC is designed based on the human control process. FL technology depends on the utilization of engineering process and product experience and its results in designing the rule base. This eliminates use of complex mathematical modeling to reach up to the control solution. The concept of fuzzy sets and fuzzy logic was initiated in the year 1965[1]. The first implementation of FL in control systems was accomplished in 1974[2]. Since then FL has been implemented to control many industrial processes, such as robot control[3], jet engine fuel control[4], traffic junction signals control[5] and furnace temperature control[6] etc. Commonly the FLC is being designed using the error of output and derivation of the error. The same is used [10] to design a FLC for the control of HRSG. Recently a simple structure has been proposed [9], which uses the error of output and integral of it to design the FLC. However getting information of derivation is not so easy. In this article, this simple structure is used to develop a FLC to control the HRSG.

In these days of escalating fuel costs, frequent power outages many of the industries are opting for co-generation. There is a need of getting energy recovery from low and somewhat medium available sources. Waste heat recovery is of prime importance to use the energy efficiently in the industrial process. Recovery of heat exhausted from industrial process and combustion can improve thermal efficiency also. HRSG is the equipment used to recover the heat from exhaust gases and to generate steam. A simplified model of boiler for system dynamic performance studies was presented in 1991[7]. We have proposed a simplified HRSG model [8] and is also considered. It is controlled by the designed FLC. Performance of the FLC is studied by simulation. The output of the results is compared with a traditional PI controller.

II HEAT RECOVERY SYSTEM

Fig.1 shows the schematic diagram of a typical heat recovery steam. It consists of a drum, evaporator, super heater (SH), steam turbine (ST) and electrical generator (G). It has both the gas turbine (GT) exhaust and supplementary fuel as inputs.

The energy in the form of heat in the GT exhaust or fuel which is supplementary is utilized to generate steam in the evaporator. The steam generated touches to the top position of the drum, from there it goes to the SH, and gets further heated and converted in to saturated steam. This steam is used to drive a ST, which is coupled to an electrical generator.

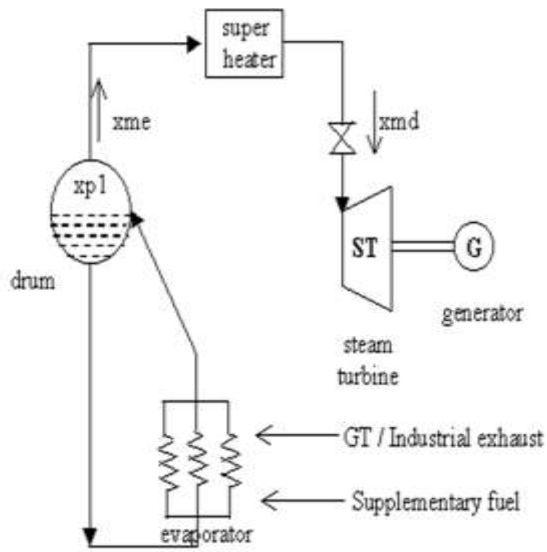


Fig.1 Schematic diagram of a HRSG

III SYSTEM MODEL

Fig.2 shows the transfer function block diagram of heat recovery system used in this paper. The blocks in the Figure 2 represents transfer function associated with equipment. There are various blocks representing the transfer function of the associated equipment. The figure also shows the connection of the input and output variables of each block. Parameter notable information is given in the Appendix (Table.1).

The input GT exhaust is a block Blspm in Figure 2. It is given to the equipment of steam generation. The output xme represents steam generation output. The output of steam generation equipment is represented by xme. This steam reaches the top portion of drum and then goes to the SH, where it will be further heated and converted in to saturated steam.

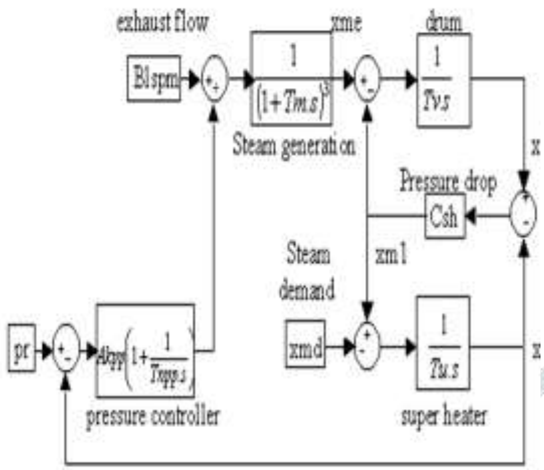


Fig.2 Heat recovery system Architecture (Block Diagram)

In real time functioning, a HRSG may be subjected to many disturbances. A pressure controller (PC) is used in the system for controlling the steam generation a pressure. The PC actuates based on the difference between the SH steam pressure xp and the pressure controller set point pr. In a conventional control system, a PI controller is used as a pressure controller. A fuzzy logic controller (FLC) is used as a PC and its performance is compared with a PI controller.

IV DESCRIPTION OF PROPOSED CONTROLLER

Usually Fuzzy controller (FC) operation depends on qualitative knowledge about the system being controlled. We must first identify the properties required. Then selection of FC input variables is correspondingly dependent on characteristic controlled system as shown in the Figure3. It shows the response y as the controlled system output and w as desired value of output w.

For the alternative, if "derivation e" is not going to utilize as one of the controller inputs then it becomes must to find some other variable which provide controlled system state information. It is the integral from the control deviation. As Figure 3 shows, this integral remains constant at value C_w. The value C_w is dependent on the w magnitude. Therefore, we have to take e1 and e2 as the fuzzy controller input variables, as per the following formulae:

$$e1(k) = w - y(k) \quad \text{........ 1}$$

$$e2(k) = \int (w - y(k))dt \quad \text{...2}$$

by neglecting C_w.

V DESIGN OF FLC

In the proposed system, FLC uses itself as PC to control the HRSG. Fig.4 shows the diagram of a heat recovery system with FLC. In the Figure 4, there is inputs to the FLC. These are error $e1_{(k)}$ and integral of error $e2_{(k)}$.

The inputs $e1_{(k)}$ and $e2_{(k)}$ are multiplied by the scaling or weightage factors K_{e1} and K_{e2} before feeding to the FLC. The output of the FLC is also multiplied by a factor K_u. These scaling factors are used to tune the controller to get the desired response.

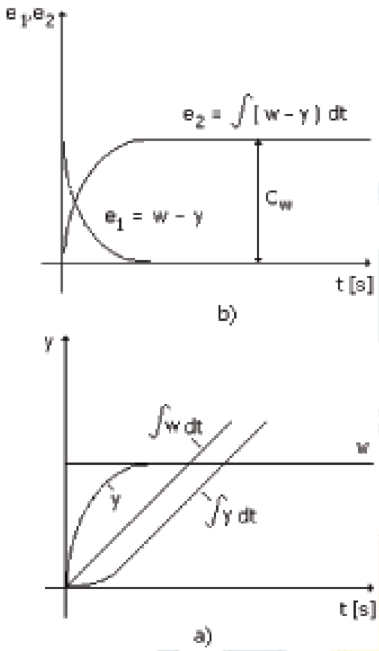


Fig.3 Characteristics of the controlled system

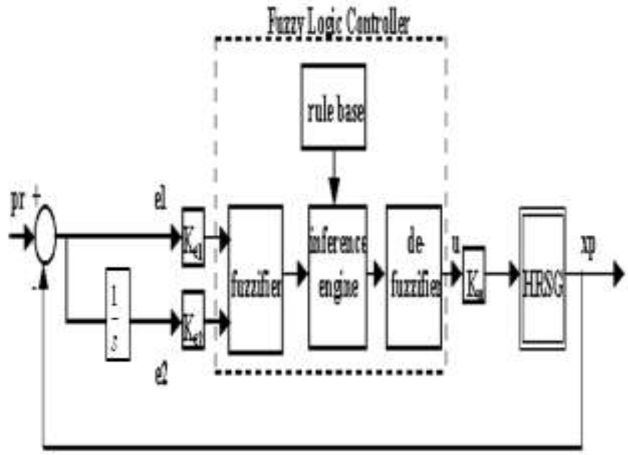


Fig.4 Heat recovery system with FLC

As shown in the fig.3 FLC contains a fuzzifier, inference engine, rule base and de-fuzzifier and it has two inputs and one output.

FUZZIFICATION

The fuzzification block converts real world variables in to fuzzy sets. For deciding the no. of fuzzy sets and their parameters, one has to decide the universe of discourse (UD). The UD is the range on which the selected variable varies. In this paper UD is taken as [-1,1] for both the inputs and output. After selecting the UD the no of membership functions and their shape and ranges are to be selected.

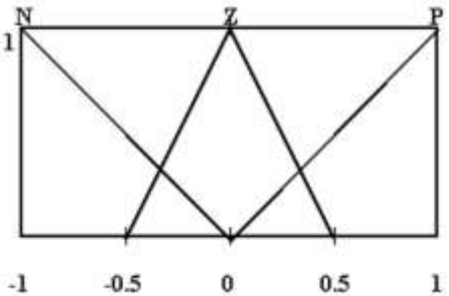


Fig.5 (a) membership function with input variables ‘e1' & ‘e2’

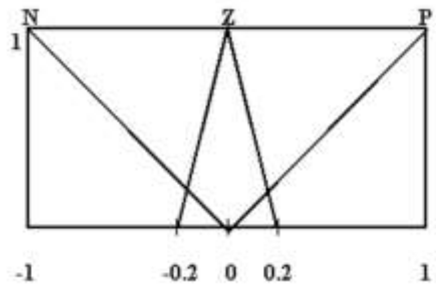


Fig.5 (b) Membership function with output variable ‘u’

As shown in the fig.5 (a) all the variables have three membership functions known as,

N	=	negative
Z	=	zero
P	=	positive

All of these three membership functions are triangular functions. The range of Z set is set to small for decreasing the steady state error. The range of Z set is made small for the output function. To reduce programme execution time only three membership functions are considered.

RULE BASE

A control algorithm is inserted and coded using the fuzzy statements in the block. It contains the rule base. It takes in to account the control objectives and the system behavior. Fuzzy rules always describe the qualitative relationship between variables in linguistic terms. Knowledge based system is implemented instead of developing a mathematical model of the system. The number of rules in the rule base depends on the number of linguistic variables. As shown in the fig.6 9 (3 x 3) rules are used to control the heat recovery system.

		e1		
		N	Z	P
e2	N	N	Z	P
	Z	N	Z	P
	P	N	Z	P

Figure 6 Rule base

A any rule is generated utilizing the control knowledge of engineering. In this paper the heuristic method is applied to build the base for the rule.

r_i : *IF* e1 is N and e2 is N *THEN* Δu is N
……3

Where r_i denotes the i_{th} fuzzy rule, i =1, 2, 3……, n. In the above rule the first part i.e., up to the word *THEN* is known as a antecedent and the part after the word *THEN* is known as the consequent. Consequent is the control action to be taken based on the antecedent.

INFERENCE ENGINE

The basic inference engine function is to compute the overall value of the fuzzy control output. It is based on the individual contributions of each rule in the rule base. In this work, the direct inference system is applied. It directly determines the outputs from the knowledge base. It also determines on line data by min-max operation. It simply transfers the operators' know-how in to the control system serving *IF-THEN* rules with membership functions.

DEFUZZIFICATION

For real life applications we need a crisp output to control the systems. The process of converting an aggregated fuzzy set in to a crisp value is known as defuzzification. It is the simple action in which the fuzzy quantities defined over the output membership functions. These are mapped then into non fuzzy number. In this work, center of gravity (CoG) method is applied. The control output Δu is determined using the following expression.

$$\Delta u = \frac{\Sigma\,(\text{Membership of i/p x o/p corresponding to respective membership of i/p})}{\Sigma\,(\text{Membership of i/p})}$$

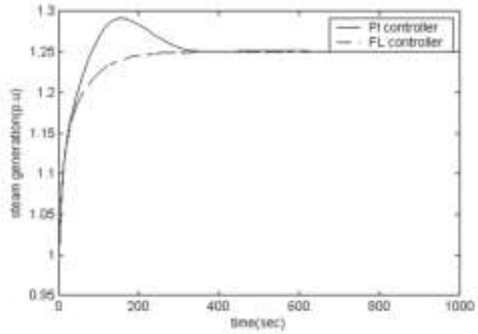
$$\Delta u = \frac{\sum_{j=1}^{49} \mu_j u_j}{\sum_{j=1}^{j=49} \mu_j} \qquad \text{……4}$$

VI SIMULATION AND RESULTS

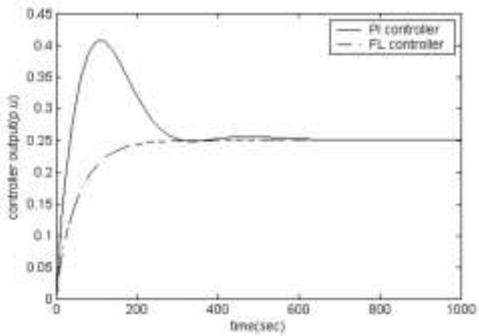
In the practical application a HRSG may be subjected to various disturbances such as sudden changes in steam demand, variations in GT exhaust etc. During these disturbances the pressure controller has to control the system. In order to study the control action of the designed FLC, a heat recovery system is modeled as per fig.2 using MATLAB software. The response of the system with FLC is compared with the conventional PI controller. The following two cases are considered for the simulation study.

Case 1. Sudden increase in steam demand by 0.25 pu
Case 2. Sudden decrease in steam demand by 0.25 pu

Fig.7 shows the effect of sudden increase in steam demand on HRSG response. Initially steam demand was 1.0 pu, which is suddenly increased to 1.25 pu. When the steam demand suddenly increases, the

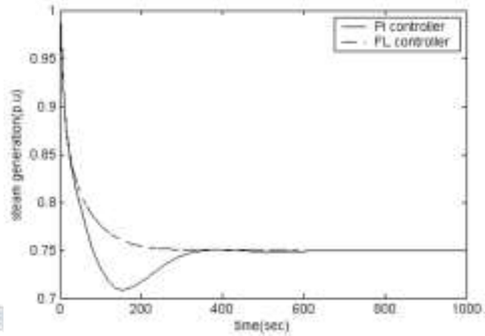


(a)

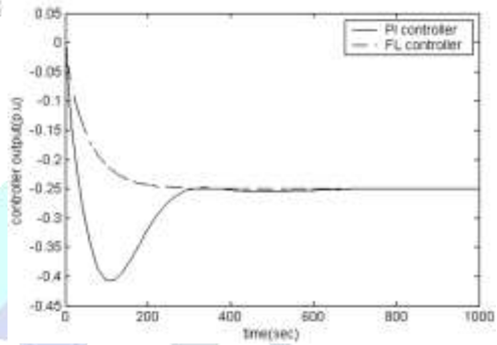


(b)

Fig .7 HRSG response for case-1



(a)



(b)

Fig.8 HRSG response for case-2

steam pressure in the SH falls immediately, which actuates the pressure controller. The pressure controller immediately increases the exhaust input to the steam generation system to meet the steam demand. Fig 7(a) shows the variation of steam generation for case-1. There is a overshoot of 0.04p.u with the conventional PI controller, where as there is no over shoot with the FLC. Fig 7(b) shows the controller's output variation for case-1. In order to meet the increased steam demand the controllers output increases sharply in positive direction to increase the exhaust input to the steam generation system. But with a conventional PI controller, there is a overshoot of 0.17 pu.

Fig 8 shows the effect of sudden decrease in steam demand on HRSG response. Initially steam demand was 1.0 pu, which is suddenly decreased to 0.75 pu. When the steam demand suddenly decreases, the steam pressure in the SH immediately raises, which actuates the pressure controller. The pressure controller immediately decreases the exhaust input to the steam generation system to meet the new steam demand. Fig 8(a) shows the variation of steam generation for case-2. There is a undershoot of 0.04 pu with the conventional PI controller, where as there is no undershoot with the FLC. Fig 8(b) shows the controllers output variation for case-2. In order to meet the decreased steam demand the controller's output increases sharply in negative direction to decrease the exhaust to the steam generation system. But with a conventional PI controller, there is a undershoot of 0.17 pu.

VII CONCLUSIONS

In this paper a simple FLC structure proposed recently is used to act as a pressure controller for the HRSG. The response of the system with the developed FLC and a conventional PI controller is studied. The common FLC design uses error and derivation of error as inputs, But in this paper error and integral of error are used as inputs to the FLC. According to that the rule base is designed. The conventional controller design needs in detail understanding of the system, exact required mathematical models and precise numerical values. A basic feature of process FLC is to control without the knowledge of its underlying dynamics. The control strategy learned through experience is expressed by a set of rules. These rules describe the state and behavior of the controller using linguistic terms. Proper control action can be retrieved from this rule base that duplicates the role of a human operator. Computer simulation has been conducted for PI, FLC based systems using MATLAB software. The results shows that the designed FLC outputs more improved control performance than the PI controller.

APPENDIX

Table.1 Model Parameters

	Parameter	Value
Akpp	HRSG pressure controller gain	2.69
Tnpp	HRSG pressure controller time constant	220
Csh	Pressure drop	2.864
Tm	Steam generation system time constant	10
Tv	HRSG drum time constant	136
Tu	Super heater time constant	53
Blspm	GT exhaust	1.0
Pr	Pressure controller set point	1.0

REFERENCES

[1] L.A.Zadeh, "Fuzzy sets", Inform.Control, Vol.8, pp 339 – 353, 1965

[2] E.H.Mamdani, "Application of fuzzy algorithms for control of simple dynamic plant", Proc.IEE 121(12), pp 1585–1588, 1974

[3] I.S.Akkizidis, G.N.Roberts, P.Ridao, J.Batlle, "Design a fuzzy like PD controller for an under water robot", Control engineering practice, pp 471 – 480, 2000

[4] A.Zilouchian, M.Juliano, T.Healy, J.Davis, "Design of fuzzy logic controller for a jet engine fuel system", Control engineering practice, Vol.8, pp 873 – 883, 2000

[5] C.H.Chou, J.C.Teng, "A fuzzy controller for traffic junction signals", Information sciences, Vol.43, pp 73 – 97, 2002

[6] Z.R.Radakovic, V.M.Milosevic, S.B.Radakovic, "Application of temperature fuzzy controller in a indirect resistance fur- nace", Applied energy, Vol.73, pp 167-181, 02

[7]F.P.De mello, "Boiler models for system dynamic performance studies", IEEE trans. on power systems, vol.6, No.1, pp 66-74, 1991

[8] Dr.Ing. Gunter Klefenz, "Automatic control of steam power plants", 3rd revised edision, Hartman & Brann AG, Minden.

[9]Pavol Fedor, Daniela Perdukova, "A simple fuzzy controller structure", Acta

Electro technica Informatica,Vol.5, No.4, pp 1-4, 2005

[10]A.Gangadhara Rao, MSR.Murthy, "Fuzzy logic control of a HRSG", proc. Int conf on emerging trends in Electrical engg., Kolkata, pp 30-34, 2007

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