Effect of Output Error on Fuzzy Interface for VDRC of Second Order Systems

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ABSTRACT
This paper presents novel method to obtain the effect of output error of the plant on variable damping ratio controller (VDRC) using fuzzy rules Interface. In this system the controller parameters $\boldsymbol{K_p}$, $\boldsymbol{K_i}$ and $\boldsymbol{K_d}$ are controlled by fuzzy rules according to the output error and its derivative. It is observed that as value of output error increases, values of controller $\boldsymbol{K_p}$ is decreases on the other hand $\boldsymbol{K_i}$ and $\boldsymbol{K_d}$ are increases. At the same time, it is also observed that the increase in the value of output error will decrease the value of damping ratio and thereby increase in the stability of the system. This novel method is very useful because of their simplicity, robustness and successful practical applications. The simulation of fuzzy rule on PID Controller is done on MATLAB version 2013. The result obtained is matched with the experimental Data. The performance of the PID controller having variable damping ratio has improved significantly compare to conventional PID controller. The simulation waveforms are included to validate the results.

Keywords
Damping Ratio, Fuzzy Interface, MATLAB, PID.

1. INTRODUCTION
In any control application, that involve PID controller, proper tuning is very important aspect. In PID tuning, three parameters of PID controller is changed so as to have optimal closed loop performance [1]. The conventional controller doesn't incorporate the human intelligence. So in our work, to embed some kind of intelligence in the PID controller, Fuzzy logic based auto tuned PID controller has been designed. The Fuzzy controller is different from conventional controller as it attempts to implement the operator's knowledge rather than mathematical equations of plant. It has been known that PID controller is used in more than 90% of process control industry. If exact mathematical model of system to be controlled is not known, PID controller is very effective. PID controller is a control loop feedback structure [2]. Difference between measured process and desired value (set - point) is said to be "error" and tries to minimize this error by doing appropriate adjustment in the process input. The PID controller has three different parameters; the proportional, the integral and the derivative. Proportional, Integral and Differential (PID) control structure is simple, easy to realize and can improve the system's dynamic and static performance [3-4]. But because conventional PID controller can not adjust the fixed PID parameters on line and on real time according to the system's actual work situation, the system's stationary and control precision will not have satisfactory result [5-6], so other compensation methods will be used for practical application[7-9], and PID parameters can be adjusted on line by fuzzy reasoning method for these compensation methods [10-13]. The Fuzzy PID controller is driven by a set of control rules rather by the three constants proportional, integral and derivative. Fuzzy controller has database and rule base, the function of database is to provide necessary information to the rule base in the form of membership function. Since PID transfer function is a second order system, it can be expressed in terms of damping ratio and undamped natural frequency to have the following form in equation (1) and (2):

$$G_{PID}(s) = \frac{K_D\ [s^2 + \frac{K_P\, S}{K_D} + \frac{K_I}{K_D}]}{s}$$

$$= \frac{K_D\ [S^2 + 2\,\xi\,\omega_n\, S + \omega_n^2\ ]}{S} \qquad (1)$$

$$\omega_n^2 = \frac{K_I}{K_D} \quad \text{and}$$

$$2\xi\omega_n = \frac{K_P}{K_D} \qquad (2)$$

2. PID CONTROLLER TUNING
Ziegler Nicholas Method (ZN) is one of the best and widely used methods of tuning available now. It provides basic knowledge for PID Tuning. "Tuning" is the name given to adjustment of the three parameters of the PID controller so as to obtain desired or optimal closed loop performances. In other words, Tuning optimizes any process by selecting appropriate value for three PID parameters.

2.1 Fuzzy Logic Approach
Fuzzy logic is a logic having which has much value rather than any exact value. Many values in binary logic reasoning is crisp whereas in Fuzzy logic reasoning has vague boundary, or it can be said that it has approximate value. The variables in fuzzy logic indicate any value between 0 and 1, so fuzzy logic system is able to deal the values of the variables those lies between completely truth and completely false. These variables are called linguistic variables; each linguistic variable is denoted by a membership function which has a some degree of membership value at any instance. Fuzzy logic carries make decision by embedding human knowledge to the system. Fuzzy inference system is the important unit of a fuzzy logic system. In fuzzy logic decision making is an important part of the entire system. The fuzzy inference system makes appropriate rules. Based upon human knowledge and experience the rules are created. The fuzzy inference system makes "IF-THEN" statements and with the help of connectors present (such as OR), necessary decision are made. The fuzzy inference system in Fig.1 takes fuzzy sets

as input and produces output t fuzzy sets. The fuzzy rule base is called knowledge base of fuzzy system because it stores all rules of the system Fuzzy inference system make necessary decision necessary to produce a desired output. In most of the application, where a controller is used, it is required to have crisp or exact values of the output rather than fuzzy (vague) values. Therefore defuzzification is required, which converts the fuzzy values of FIS into corresponding crisp values.

There are three main types of fuzzy inference systems are used:

- Tsukamoto model
- Mamdani model
- Sugeno model

Among these three Mamdani model is the most popular, and in this work same will be used.

There are also three main type of defuzzification method:

- Mean of maximum
- Centroid of area
- Bisector of area

In this work Mamdani fuzzification method is used. There are two types of Mamdani fuzzy inferences

- “min and max”
- “product and max”

In our work, the “min and max” Mamdani system is used. For this type of system,” min and max” operators are used in place of “AND and OR” methods respectively. Here µ is the membership value for the linguistic variables” A1, B1, A2, B2, C1, C2 and C”. The fuzzy rules for the system can be described as follows:

1. If” x is A1” and” y belongs to B1”, then “z is C1”.
2. If “x is A2” and “y belongs to B2”, then “z is to C2”.

The defuzzification method used is mean of maximum (MOM) method.

PID controller should be very precise. In practical applications, most of the industrial processes are nonlinear. There is a variation in parameter of plant and chances of external disturbance are very high. Thus by using conventional PID controller the optimal closed loop performance cannot be achieved. The problem of plant can be achieved by using fuzzy logic.

In Fig. 1 the fuzzy inference system in takes fuzzy sets as input and produces as output fuzzy sets. The fuzzy rule base is called knowledge base of fuzzy system because it stores all decision to produce a desired output. “IF THEN” rule based upon human knowledge and experience.

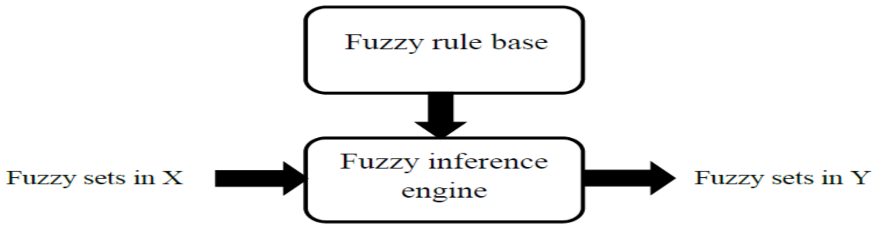

Fig.1: Fuzzy system

3. PRINCIPLE AND DESIGN OF FUZZY PID CONTROLLER

3.1 Principle of fuzzy PID Controller

PID controller is still the most popular controller which is widely used to improve the performance of the system. The performance specifications of the system can be improved by tuning value of parametersK_p, K_i and K_d of the PID system to get desired value. Fuzzy self-tuning PID Controller works on the basis of control rules, which can be obtained by theoretical and experimental analysis of any system of expert. By self tuning it mean the characteristics of the controller to change or adjust its controlling parameters on-line automatically so as to have the most appropriate values of these parameters, which help can tune the parameters K_p , K_i and K_d with the help of rule base on – line. This provides better performance than the conventional PID controller or simple fuzzy controller.

3.2 Design of self tuning Fuzzy PID Controller

The self tuning Fuzzy PID takes “error” (e) and “rate of change of error” (ec) as input to fuzzy logic controller and modify value of three PID parameter “K_p”, “K_i” and “K_d” online as output. Thus we have total of five linguistic variables (e, ec,K_i, K_P, K_d). Total of seven fuzzy values NB, NM, NS, ZO, PS, PM, PB are chosen for each of the linguistic variable. The region “e” and “ec” are between -3 to 3 whereas by doing some interpolation region of K_i',K_p', and K_d' are kept between 0 and 1. Interpolation tries to keep the value of the variable within specified region. The formula used is shown in equation (3), (4) and (5).

$$K_p' = \frac{(K_p - K_{pmin})}{(K_{pmax} - K_{pmin})} \quad (3)$$

$$K_i' = \frac{(K_i - K_{imin})}{(K_{imax} - K_{imin})} \quad (4)$$

$$K_d' = \frac{(K_d - K_{dmin})}{(K_{dmax} - K_{dmin})} \quad (5)$$

Where K_p', K_i', K_d' are previous value and K_p, K_i, K_d are modified value. Suffix max and min are maximum and minimum value of variable that we take into our consideration The linguistic rules are important part of FIS. These rules are called the rule base. These rules are created with the help of human knowledge and expertise upon behaviour of the system under different condition. Any number of such rules can be formed to give the controller direction for action. Fig. 2 shows the basic model of fuzzy PID Controller.

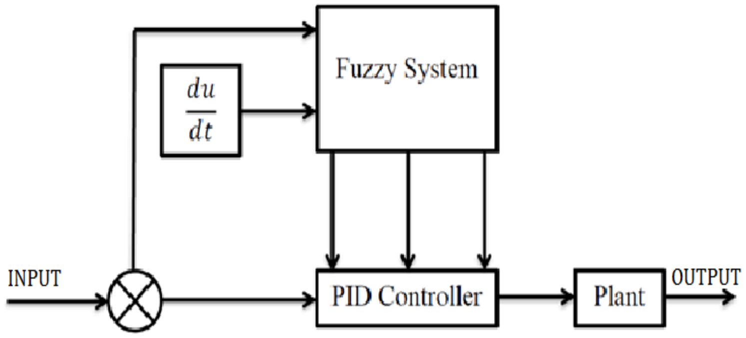

Fig.2: Basic model of a fuzzy PID controller

3.3 Fuzzy Inference System Design

In order to adapt controlled plant's uncertainty, nonlinearity, time-variability and enhance system's adaptability and robustness, it is necessary that PID controller's three parameters should be regulated on line. So, combining the advantages of PID control and fuzzy control, in order to obtain the variable damping control goal, the system's damping ratio should be changed on line using fuzzy PID controller parameters "K_p", "K_i", "K_d" according to second-order system output response's change law of e and ec. Fig. 3 shows Variable damping ratio controller's structures of fuzzy adaptive adjust PID. Rule base for K_p , K_i and K_d are shown in corresponding table 1, table 2 and table 3. Thus we have total of two input as e and ec and three output as "K_p", "K_i", "K_d" Hence by these three tables, total 49 rules are formed in FIS using MATLAB.

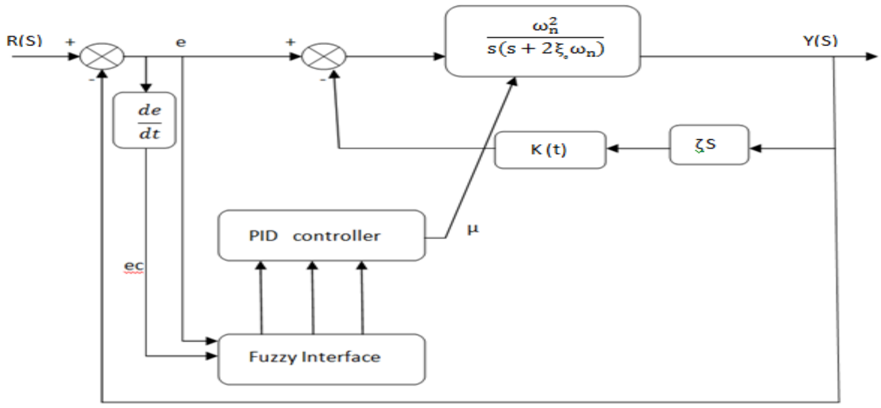

Fig. 3: Variable damping ratio controller's structure of fuzzy adaptive adjust PID

Table 1. Rule base for "K_p

e/ec	**NB**	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. Rule base for "K_i"

e/ec	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table 3. Rule base for "K_d"

e/ec	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

4. RESULT AND SIMULATION

In fig.4. two inputs and three outputs Fuzz inference system has been designed. Inputs are "error" and "rate of change of error" and outputs are three parameter$\mathbf{K_p}$, $\mathbf{K_i}$ and $\mathbf{K_d}$ of PID controller.

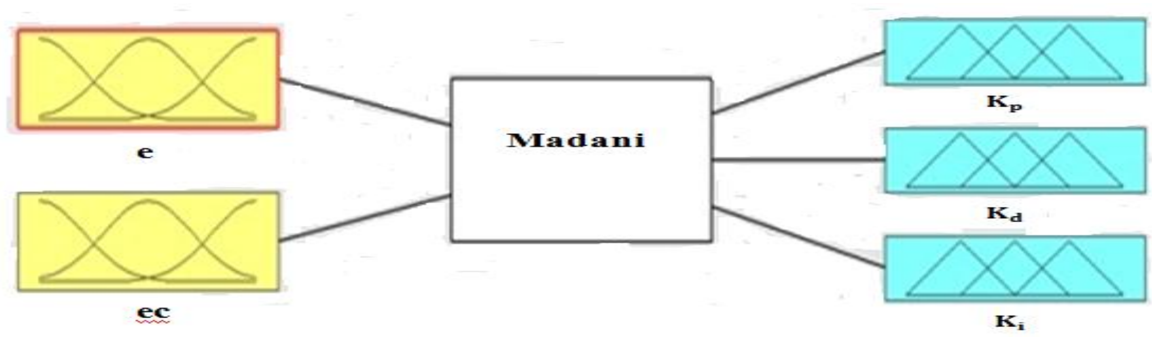

Fig. 4: FIS Design

Table 4. Effect of output error on Fuzzy Interface for VDRC of second order system

e	K_p	K_i	K_d	ξ	ω_n
-1	0.667	0.333	0.167	1.414	1.412
-2	0.667	0.333	0.167	1.414	1.412
-3	0.833	0.167	0.0523	4.45	1.786
0	0.5	0.5	0.333	0.613	1.225
1	0.333	0.667	0.5	0.288	1.155
1.5	0.25	0.667	0.583	0.126	1.0695
2	0.167	0.667	0.667	0.125	1
2.5	0.167	0.75	0.75	0.11	1
3	0.167	0.833	0.833	0.1	1

Inferences from table 4:

1) Inferences from table 4 is that as error increases value of variable damping ratio decreases.
2) It is observed that as error increases, value of controller parameter K_p decreases.
3) It is also observed that as error increases, value of controller parameter Ki and Kd increases.
4) From table 4, we can easily see as error increases, value of angular frequency is almost same.

The Fig. 5 shows Transient analysis of step response of the system. The surface plot corresponding to K_p, K_d and K_i are shown in Fig.6, Fig. 7 and Fig. 8. Member function plot with error variable shown in Fig.9.

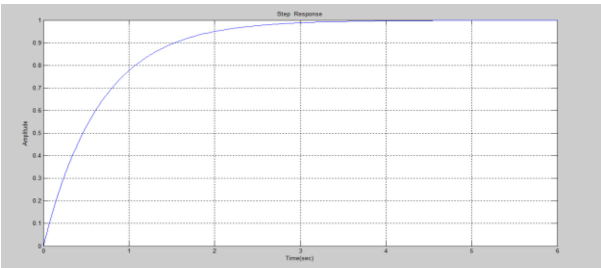

Fig. 5: Transient analysis of step response

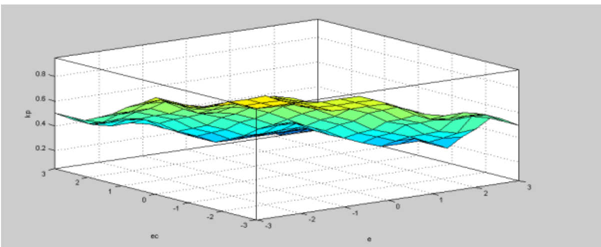

Fig. 6: Surface plot corresponding to K_p

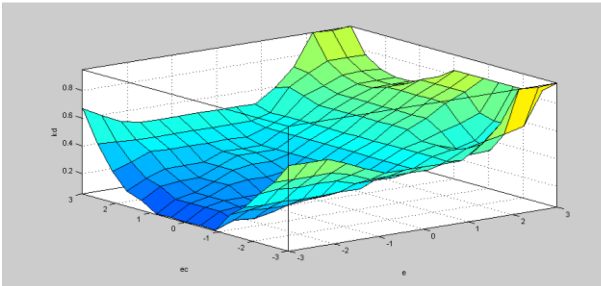

Fig. 7: Surface plot corresponding to k_d

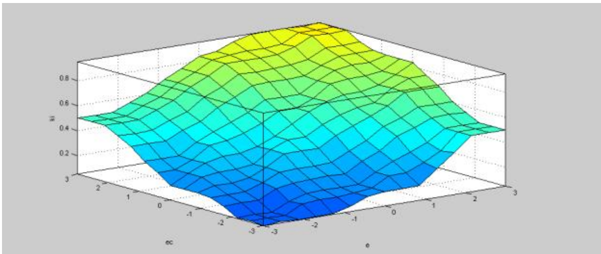

Fig. 8: Surface plot corresponding to k_i

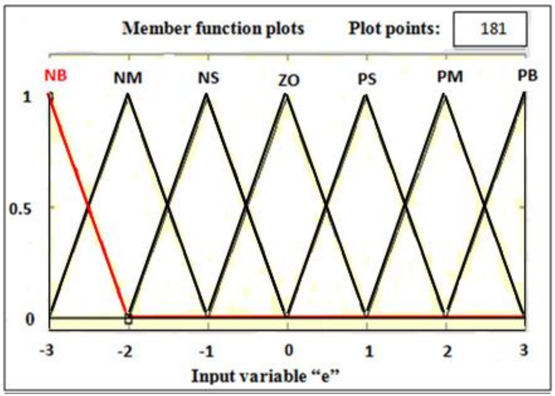

Fig. 9: Member function plot with error variable

5. CONCLUSION

As we have observe the results, when error increases at fuzzy interface, the value of variable damping ratio decreases. We find the use of above fuzzy auto tuned PID control techniques give better performance in terms of rise time, settling time, peak overshoot and most importantly robustness. The response of the system was also faster than in the case of PID controller tuned by Ziegler and Nicholas method. The application of self tuning PID controller enable controller to tune itself while operating on - line.

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