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Performance Comparison between Conventional and Self Tuning Fuzzy PI Controllers for Interacting Multivariable Process

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ABSTRACT-Conical tanks are used in many process industries as its shape contributes better drainage. The interactions between input-output variables are a common phenomenon. The implementation of control algorithms for this MIMO system is complicated,due to variation in process dynamics that occur due to nonlinear dynamic coupling.The control system present many challenging problem also due to uncertain and time varying parameters,constraints on manipulated variable,interaction between manipulated and controlled variable. The time domain analysis of interacting multivariable process is analyzed using PI controller.Then Self tuning fuzzy PI controller is applied to compare its performance.It is observed that Self tuning fuzzy PI controller perform better than conventional controller**.**

KEYWORDS: TCTILS,PI controller,fuzzy logic controller, Self-tuning fuzzy PI controllers.

I. INTRODUCTION

Conical tank is a non-linear process because of its varying cross sectional area.For industries using nonlinear process,the design of controllers is a challenging task because the controller theory mainly deals with linear processes.The implementation of MIMO system is complicated,due to the variation in process dynamics[1].PI controller is used in many process industries due to its fast response and quick tuning[2][6][7].For controlling the level of tank in a multivariable process,model based controller can be used Internal Model Control (IMC) since it provide better closed loop performance and robustness compared to other[4][13].Also a decentralized IMC method is used for controlling the multi-input multi-output plants subject to multiple operating regimes [4].Because of the introduction of digital computers for process control,the applicability of adaptive control system has widened[3].The optimal control for Two Conical Tank Interacting Level System (TCTILS) is obtained by linear quadratic Gaussian control solution with optimal Kalman filter[5].

Several intelligent techniques like Genetic algorithm are used which is a global search technique for optimization process.It mimics the process of natural evaluation[7].As PI controller are time consuming and produce damped oscillation,neural network based controller are designed to overcome it[8].A centralized neuro controller realize a good dynamic behavior of TCTILS a perfect level tracking with lesser overshoot,lesser settling time,reduced interaction and good rejection of load disturbances[16].

MPC has become the leading form of advanced multivariable control in chemical process industry[11].To maintain performance of multiple linear MPC controller over a wide range of operating levels we can introduce a gain scheduling control strategy for MPC[12].Since MIMO system cause difficulties in feedback controller design a decentralized control can be used in industrial environment.It is used because of its simple structure,ease of implementation and maintain adequate performance[15].The fuzzy logic controller are widely used since it performs with zero overshoot,faster settling time,better set-point tracking and lesser error compared to conventional controllers[17].

In this paper, through simulation in Matlab by selecting appropriate fuzzy rules are designed to tune the parameters k_p *and* k_i of the PI controller. In this study, we propose two controllers conventional PI and Self Tuning Fuzzy PI controller for a liquid level process and analysis the result. We find the improvement in system performance over the conventional PI controller by the influence of the external disturbance.The paper is organized as follows:section 2 deals with the system and modeling,section 3 contain the conventional controller implementation,details of self-tuning fuzzy PI controller and implementation is included in section 4,section 5 deals with the simulation results and finally section 6 contain conclusion.

II. TWO CONICAL TANK INTERACTING LEVEL SYSTEM

Two Conical Tank Interacting Level System (TCTILS) is a class of two tank benchmark setup used by researchers. TCTILS is a nonlinear TITO system whose parameters vary with operating point. TCTILS has nonlinear dynamic interaction. The TCTILS as shown in Fig1 is based on the two tank benchmark setup that has been used by a number of researchers. The TCTILS is regarded as a setup for investigating, theoretically and experimentally, nonlinear multivariable feedback control schemes. TCTILSconsists oftwo identical conical tanks (TANK1 and TANK2), two independent pumps (PUMP1 and PUMP2) that deliver the liquid flows F_{IN1} and F_{IN2} to TANK1 and TANK2 through the two control valves $CV_1$and CV_2 respectively. These two tanks are interconnected at the bottom through a manually controlled valve, MV_{12} with a valve co-efficient β_{12}. F_{OUT1} and F_{OUT2} are the two output flows from TANK1 and TANK2 through manual control valves MV_1 andMV_2 with valve coefficients β_1 and $\beta_2$respectively. The β_{12}, β_1 and β_2 are adjustable coefficients representing the resistance of the respective valves opening orifice.

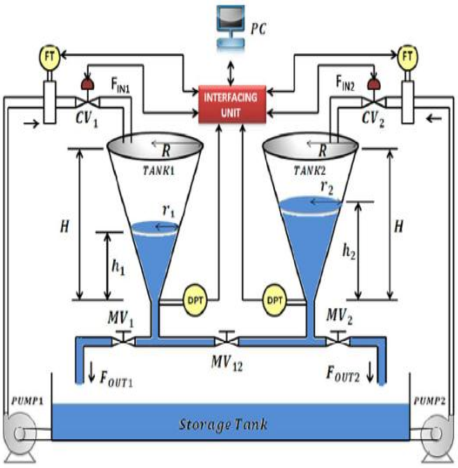

Fig1.schematic of TCTILS

The valve coefficient β_i may be evaluated using

$$\beta_i = V_i a_i \sqrt{2g} \tag{1}$$

where Vi (i = 1, 2,12) are the cross sectional area of valves and ai is the discharge coefficient, which is assumed as unity. The operating parameters of TCTILS are presented in Table1. In TCTILS, level h_2 in TANK2 is considered as measured variable and F_{IN1} is considered as manipulated variable.

The mathematical model of TCTILS is given by,

$$\frac{dh_1}{dt} = \frac{F_{IN1} - \beta_1\sqrt{h_1} - sign\,(h_1 - h_2)\beta_{12}\surd h_1 - h_2 - h_1\frac{dA\,h_1}{dt}}{\frac{1}{3}\pi R^2 \frac{h_1^2}{H^2}} \tag{2}$$

$$\frac{dh_2}{dt} = \frac{F_{IN2} - \beta_2\sqrt{h_2} + sign\,(h_1 - h_2)\beta_{12}\surd h_1 - h_2 - h_2\frac{dA\,h_2}{dt}}{\frac{1}{3}\pi R^2 \frac{h_2^2}{H^2}} \tag{3}$$

A (h_1) - Cross sectional area of TANK1 (cm^2) at h_1 cm
A (h_2) - Cross sectional area of TANK2 (cm^2) at h_2 cm

TABLE1.OPERATING PARAMETERS OF TCTILS

Parameter	Description	Value
R	Top radius of conical	19.25 cm
H	Maximum height of TANK1 & TANK2	73 cm
F_{IN1}& F_{IN2}	Maximum inflow to TANK1 & TANK2 respectively	111.11 cm^3/s
β_1	Valve co-efficient of MV_1	35 cm^2/s
β_{12}	Valve co-efficient of MV_{12}	78.28 cm^2/s
β_2	Valve co-efficient of MV_2	19.69 cm^2/s

A) TRANSFER FUNCTION OF TCTILS

The model of TANK1 can be represented as

$$\mathrm{A}(h_1)\frac{dh_1}{dt} = F_{IN1} - \beta_1\sqrt{h_1} - h_2 \quad (4)$$

Linearzingand applying partial differentiation and Laplace transform the above equation becomes,

$$\partial h_1 = \frac{\partial F_{IN1} + \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}}\partial h_2}{A(h_1)s + \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}}} \quad (5)$$

The model of TANK2 can be represented as

$$\mathrm{A}(h_2)\frac{dh_2}{dt} = \beta_1\sqrt{h_1} - h_2 - \beta_2\sqrt{h_2} \quad (6)$$

Linearizing and applying partial differentiation and Laplace transform the above equation becomes,

$$[A(h_2)s + \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}} + \frac{\beta_2}{2\sqrt{h_{2o}}}]\partial h_2 = \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}}\partial h_1 \quad (7)$$

Substitute (5) in (7) we get

$$[\ A(h_2)s + \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}} + \frac{\beta_2}{2\sqrt{h_{2o}}}\ ]\partial h_2 = \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}} \frac{\partial F_{IN1} + \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}}\partial h_2}{A(h_1)s + \frac{\beta_1}{2\sqrt{h_{1o}} - h_{2o}}} \quad (8)$$

Assuming different values for each terms we get the transfer function of TCTILS relating h_2 and F_{IN1} as

$$\frac{\partial h_2}{\partial F_{IN1}} = \frac{R_2}{\tau_1\tau_2 s^2 + [\tau_1 + \tau_2 + A(h_1)R_2]s + 1} \quad (9)$$

Where $$c_1 = \frac{1}{2\sqrt{h_{1o}} - h_{2o}} c_2 = \frac{1}{2\sqrt{h_{2o}}}$$

$$R_1 = \frac{1}{\beta_1 C_1} R_2 = \frac{1}{\beta_2 C_2}$$

$$\tau_1 = A(h_1)R_1\tau_2 = A(h_2)R_2$$

III. PI CONTROLLER

PI controller is used in many process industries due to its fast response and quick tuning.PI stands for proportional-integral controller.In complex industrial control systems the main building block of control network include a PI controller.It calculates the error value as the difference between a measured process variable and a desired set-point.The PI controller tries to minimize the error by adjusting the process control input.PI is simple,robust and widely used in many control applications.

Mathematically

$$m(t) = K_p e(t) + K_p \frac{1}{T_i} \int e(t)dt \qquad (10)$$

In proportional controller the error value is multiplied by a proportional gainK_p.It is also called adjustable amplifier.It is responsible for the process stability. Integralerror is multiplied by K_I.In many systems integral gainsare responsible for driving error to zero. But high value of gain results in oscillations and instability.Servo and Regulatory response of PI is observed.The gain values of PI is obtained as shown in the Table 2,

TABLE2.GAIN VALUES OF PI CONTROLLER

CONTROLLER	K_P	K_I
PI	0.5281	1.7907

IV. SELF TUNING FUZZY LOGIC CONTROLLER

The performance specifications of the systems such as rise time, overshoot, settling time and error steady state can be improved by tuning parameters $k_p$and$k_i$of the PI controller. By developing self tuning fuzzy controllers, these parameters can be modified online, according to the changes in the process condition without much intervention of an operator.

LotfiZadeh, the father of fuzzy logic is extend two valued logic, defined by the binary pair {0,1}, to the whole continuous interval [0, 1]. Fuzzy controllers use heuristic information in developing design the control of nonlinear dynamic system. A fuzzy control system is shown in Fig. 2. FLS is consist fuzzifier, rules, inference engine and output processor (defuzzifier) and that are interconnected. The fuzzifier converts the crisp value into Fuzzy Sets. It is needed to activate rules that are in terms of linguistic variables. The rules are the heart of an FLS. The rules are expressed as a collection of IF-THEN statements. The IF-part of a rule represents antecedent and the THEN part represents consequent. The fuzzified inputs activate the inference engine and the rule base to produce a Fuzzy Set output. The commonly used inferential procedure is minimum and maximum implication method. Defuzzification is necessary to obtain the crisp number as the output.

Here we used self tuning fuzzy PI and PI controller, that is, the three parameters such as proportional gain (k_p) and integral gain (k_i) of controllers are tuned by using fuzzy tuner. The co-efficient of the classical controllers cannot be properly tuned for the TCTILSwith unpredictable parameter variation, hence tune automatically the controller parameters such ask_p and k_i values by using self tuning fuzzy PI controller. The structure of the self tuning fuzzy PI controlleris shown in Fig. 3.

The proposed controller structures consist of a simple upper level controller and a lower level classical controller. The upper level controller provides a mechanism to select the gain of a classical PI and the lower level deliver the solution to a particular situation. Here we use the control structure as a rule based Mamdani fuzzy controller. It is used in the upper level and conventional PI controller is selected for the lower level.

In fuzzy structure, there are two inputs to fuzzy inference: error $e(t)$ and change of error $de(t)$ and three outputs foreach PI controller parameters respectively k_p *and* k_i**.** The steps for designing aimed controller for the spherical type of storage vessel are as follows:

a) Select the input and output parameters for the fuzzy controller. Here we choose the error signal and the change of error signal as the input parameters and output parameters for the fuzzy controller as the proportional and the integral gain parameters

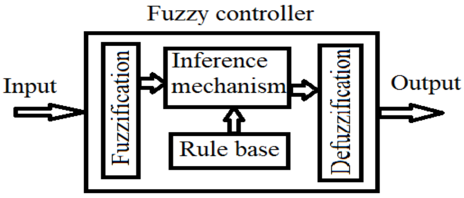

Fig. 2: A fuzzy control system

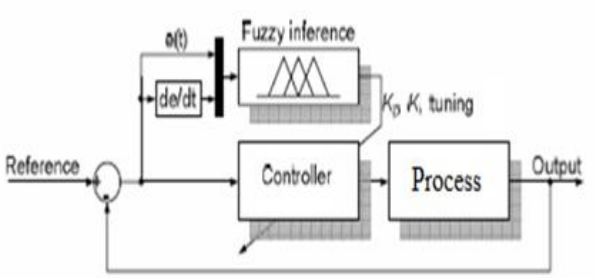

Fig. 3:The structure of the self-tuning fuzzy PI controller

b) Then divide the universe of discourse into FSs. Fig. 4 and 5 show the input membership functions for the error signal and change of error signal respectively. Here the universe of discourse is divided as Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Large (PL). Fig. 6 to 7 shows the output membership function for the proportional and integral gains, whereas the universe of discourses is divided as Medium (M), Big (B) and Very Big (VB).

c) Write the rule base for the Self Tuning Fuzzy PI controller, based on experience and it is described in the below given Table 3&4 correspondingly.

d) Use the algorithm of the amied controller:Centroid defuzzification is the best technique to obtain the crisp output.

The degree of each membership function which was computed in the previous step of fuzzifications encountered by the subprogram called defuzzify and this after certain process it returns defuzzified output.

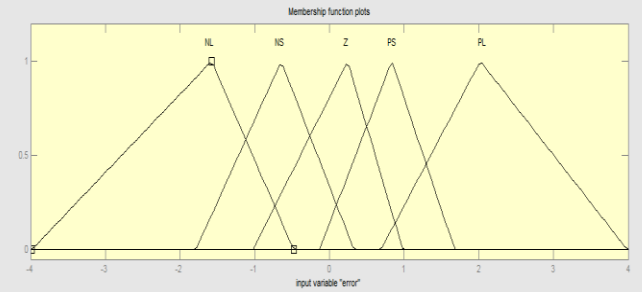

Fig. 4: Membership functions for the error signal

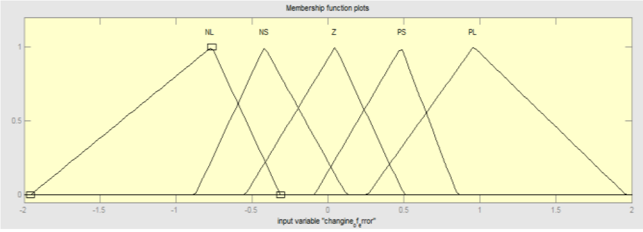

Fig. 5: Membership functions for the change of error signal

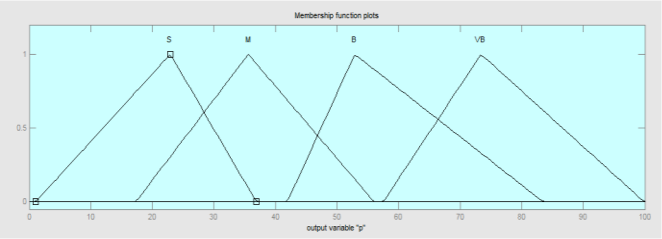

Fig. 6: Membership functions for the proportional gain

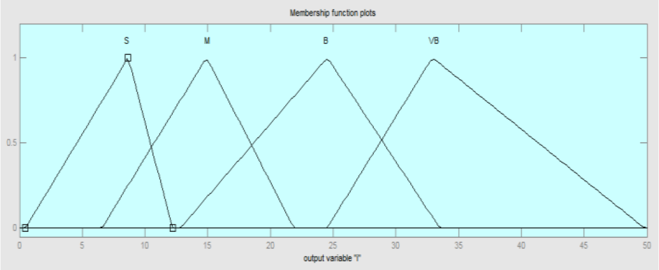

Fig. 7: Membership functions for the integral gain

TABLE 3: RULE BASE FOR THE PROPORTIONAL GAIN

e Δe	NL	NS	Z	PS	PL
NL	M	S	S	S	M
NS	B	M	S	M	B
Z	VB	B	M	B	VB
PS	B	M	S	M	B
PL	M	S	S	S	M

TABLE 4: RULE BASE FOR THE INTEGRAL GAIN

e Δe	NL	NS	Z	PS	PL
NL	B	M	S	M	B
NS	B	M	M	M	B
Z	VB	B	M	B	V
PS	B	M	M	M	B
PL	B	M	S	M	B

V. SIMULATION RESULTS

Simulation results of servo and regulatory responses are provided. The Self tuning fuzzy PI controller is designed and applied to the TCTILSsystem. The performance of the Self tuning fuzzy PI controller is compared with conventional PI controller using MATLAB/Simulink responses. The servo and regulatory responses of PI controller and Self tuning fuzzy PI controller are shown in Fig.8 and 9. It is observed that the level oscillates very much high for PI and whereas oscillation is very much less in Self tuning fuzzy PI controller. Also it is observed that in Self tuning fuzzy PI controller tracks the set point in less time compared to PI controller. Self-tuning Fuzzy PI controller follows smooth tracking towards the given set point. The performances of controllers are also examined using ISE, IAE and ITAE and their values for Self-tuning fuzzy PI controller is less compared to conventional PI controller in all the operating region. The performance indices in terms of ISE, IAE and ITAE for servo and regulatory response are also shown in Table 5&6.

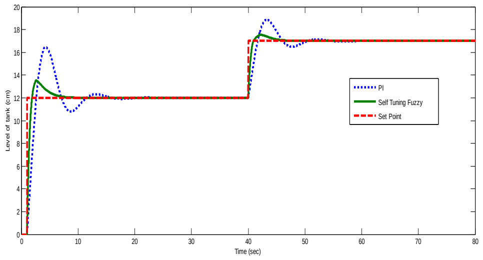

Fig.8PI & Self tuning fuzzy PI servo response

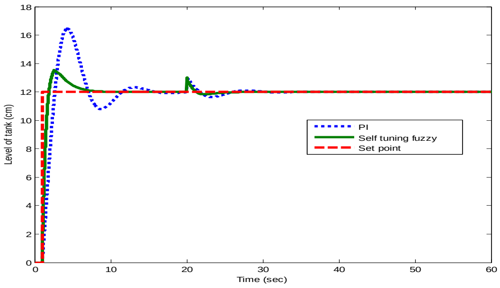

Fig.9 PI & Self tuning fuzzy PI regulatory response

TABLE 5: PERFORMANCE COMPARISON (SERVO RESPONSE)

Controller	ISE	IAE	ITAE
PI	142.3	36.93	589.8
Self-tuning fuzzy PI	35.7	10.82	152.1

TABLE 6: PERFORMANCE COMPARISON (REGULATORY RESPONSE)

Controller	ISE	IAE	ITAE
PI	122	28.11	165.3
Self-tuning fuzzy PI	30.81	8.61	40.76

VI. CONCLUSION

Nonlinearity of the conical tank is observed and the model is implemented using SIMULINK.Level control of TANK2 is checked by both PI and Self tuning fuzzy PIcontroller.From the simulation results we can observe that both Self tuning fuzzy PI and PI provide fast response but Self tuning fuzzy PI control perform well with less number of oscillations when subject to change in level of conical tank and enhance performance of the system.

Self-tuning fuzzy PI controller gives better performance than conventional controller for both servo and regulatory problems in terms of integral time weighted absolute error,integral square error,and integral absolute error.Therefore we can conclude that Self tuning fuzzy PI controller is working properly for both servo and regulatory problems of two conical tank interacting level system.

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