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A Genetic Algorithm Tuned Fuzzy Controller for a Nonlinear Process

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Abstract: This study addresses the design of Genetic Algorithm (GA) based fuzzy controller for the non linear process. The process taken for this study is conical tank since most of the chemical industries use the same. The model of the process is identified by introducing a step change in inlet flow rate to the tank and recording the change in level with respect to time. The recorded data is plotted against time which is process reaction curve. From the process reaction curve the model parameter of the process is identified. For the identified model different controllers such as Internal Model Controller (IMC), fuzzy and GA based fuzzy controllers are designed and implemented in MATLAB environment. It was observed that GA based fuzzy controller outperformed the other controllers in terms of performance indices such as Integral Square Error (ISE), Integral Time Absolute Error (ITAE) and Integral Absolute Error (IAE) and Time domain specifications.

Key words: Non-linear system, process modeling, internal model control, fuzzy logic, genetic algorithm

INTRODUCTION

Most nonlinear processes are seen in chemical industries. Controller design for such nonlinear process is found to be a major problem. The conventional PID controllers are widely used in many industrial processes for several decades (Ziegler *et al*., 1942). The new tuning rule has proposed for a robust performance for a process based on a step response (Astrom and Hagglund, 2004). However, due to the nonlinear effects their performances are limited. The nonlinear structural characteristics of intelligent controllers can be effectively deployed to model plant dynamics which improves the overall quality of the end product to a good extent. Modern day chemical industries requires tanks with varying shapes and conical tank plays a important role for certain specific applications and its level control is important because it varying cross sectional area gives rise to nonlinearity.

The Fuzzy controller is suitable for the level control of the conical tank and it is identified from literature that conventional controllers are not providing satisfactory results under varying set point and load conditions. Since the initiation of the fuzzy sets (Zadeh, 1965) and its industrial application (Mamdani, 1974) fuzzy systems have received much attention in engineering systems. The method for stabilization of nonlinear systems using Takagi-Sugeno model is designed (Wang *et al*., 1996).The fuzzy logic control system predominantly is considered more effective than the conventional PID control system that assures reduced batch time and energy consumption (Fileti *et al*., 2007). The design of fuzzy based intelligent control schemes are proposed for heat exchanger and coupled tank system (Jain *et al*., 2011) and conical tank system (Sowmya *et al*., 2012).

In fuzzy logic control systems, the rules are basically formed by the trial and error method and hence an optimized result is not obtained. In order to find the appropriate tuning values from the search space, genetic algorithm can be used which efficiently find the optimal parameter based solutions for complex control systems. An innovative method of tuning PID controller using GA is developed (Herrero *et al*., 2002) and process optimization technique using GA to reduce the number of rules in a fuzzy controller to produce an optimal solution is also developed (Kumar and Vijayachitra, 2009).

The tuning of fuzzy controller using genetic algorithm by optimizing the parameters without changing the membership functions was discussed by Borut (Zupancic *et al*., 1993). In this study, an optimized GA based fuzzy logic controller is proposed for the application of level control in a conical tank. The step response characteristics are experimented favorably for the determination of the process model. Chen and Fruehauf's based PID controller settings are used for tuning of controller (Chien and Fruehauf, 1990) and the performances of the traditional PID controller are analyzed with the proposed controller based on time domain specifications and performance indices.

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DEVELOPMENT OF MATHEMATICAL MODEL

The dynamics of the conical tank system which shows non linearity is analyzed in four regions to obtain the appropriate models and the regions are 0-15 cm for model 1, 15-27 cm for model 2, 27-36 cm for model 3 and 36-43 cm for model 4 . The mathematical model for each operating range is obtained. The schematic diagram of the conical tank system is shown in Fig. 1. To obtain the model of the system, the analysis of the system is done by performing the open and closed loop tests. From the analysis, the model for the four regions is obtained. The real time system contains a conical tank, water pump and reservoir, compressor, current to pressure converter, differential pressure transmitter, ADAM module and a computer that acts as a controller. The input current for regulating the valve position is 4-20 mA. It is given in the form of 3-15 psi pressure with the help of a compressor.

The inlet flow rate to the tank is regulated by adjusting the stem position of the pneumatic valve. The control signal to the valve is given by the computer through the digital to analog converter of the ADAM module. The differential pressure transmitter is for level of the tank. This transmitter is calibrated for the entire height of the tank which is converted into 4-20 mA output current. The module is operated with the help of MATLAB software.

SYSTEM IDENTIFICATION

By applying step response method, the response of the tank level is obtained for the given input flow. From this response, the parameters required for finding the model are obtained. Due to nonlinearity in shape of the tank, single model will not be accurate, so various trials were conducted to find the response of the entire tank in four different regions. These models are obtained from the open loop response of the system. The models found by the sunderesan kumaraswamy method (Sundaresan and Krishnaswamy, 1978). As per the response curves, the models obtained are found to be First Order plus Delay Time (FOPDT) process given as:

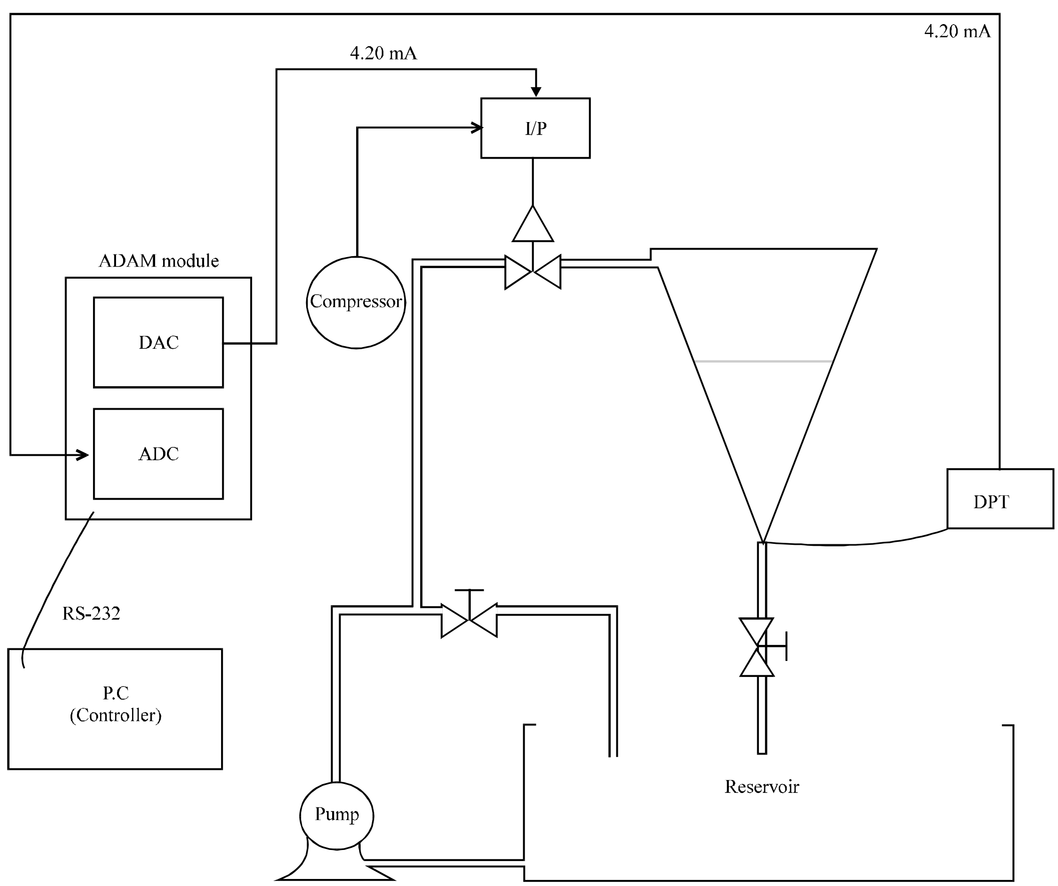

Fig. 1: Schematic diagram of conical tank system

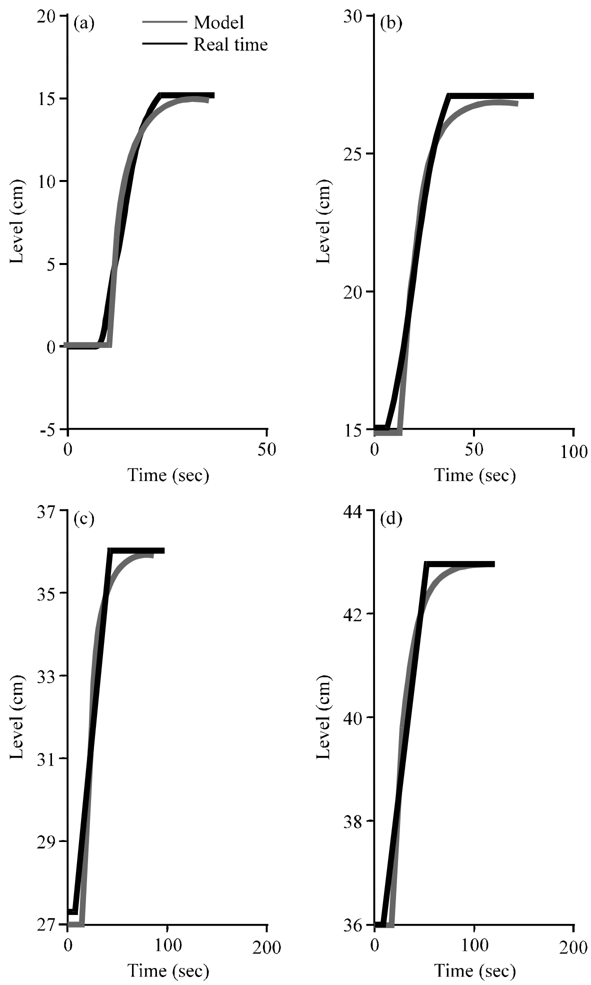

Fig. 2 (a-d): Comparison of experimental and simulated response for four different models. (a) Model 1, (b) Model 2, (c) Model 3 and (d) Model 4

$$G(s) = \frac{ke^{-\theta s}}{\tau s + 1} \tag{1}$$

where, k is process gain, θ is delay, τ is time constant.

The maximum inflow rate is maintained at 7 lpm. The models for the four operating regions are estimated as given below.

For region 0-15 cm:

$$G(s)_{model\,1} = \frac{2.14e^{-10.7s}}{4.11s + 1} \tag{2}$$

For region 15-27 cm:

$$G(s)_{model\,2} = \frac{1.71e^{-13.68s}}{8.978s + 1} \tag{3}$$

Table 1: Controller parameters for models of conical tank system

Parameters	Model 1	Model 2	Model 3	Model 4
K_p	0.174	0.340	0.471	0.538
K_i	0.018	0.021	0.023	0.022
K_d	0.404	1.335	2.238	0.167

K_p: Proportional gain, K_i: Integral gain, K_d: Derivative gain

For region 27-36 cm:

$$G(s)_{model\,3} = \frac{1.28e^{-15.71s}}{11.99s + 1} \tag{4}$$

For region 36-47 cm:

$$G(s)_{model\,4} = \frac{e^{-17.96s}}{14.72s + 1} \tag{5}$$

The four models are validated by giving a step input and the simulated curves are obtained. The step input for all four set points are given to the system and the real time curve is obtained. The experimental and simulation response curves for all the models are compared as shown in Fig. 2a-d, respectively.

From the graphs, it is clear that the model response curve obtained is closer to that of the real time response curve for all the four models.

DESIGN OF CONVENTIONAL CONTROLLER

In this study the IMC-based PID controller settings based on Chien and Fruehauf method are tuned for all the four models and the obtained controller parameters are tabulated in Table 1.

DESIGN OF FUZZY AND GA OPTIMIZED FUZZY CONTROLLER

In this study, the fuzzy controller is designed for all the four models with three membership functions as error, change in error and output and their responses are compared with the IMC-PID controller. For the obtained fuzzy output, GA optimization is done using the GA tool. Since fuzzy controller is tuned manually and the rules are written by trial and error method, the output needs to be optimized. The GA tool tunes the fuzzy controller automatically.

The population size is fixed first and the fitness function is calculated and in this study, the ITAE is taken as the fitness function. Here, the ITAE is reduced by altering the midpoints of the linguistic variables of the membership functions. This tuning of the midpoints of the membership functions are done for all the four models and the optimized output is obtained. The untuned and tuned midpoint of the membership functions for model 1 is shown in Fig. 3a-c and 4a-c, respectively.

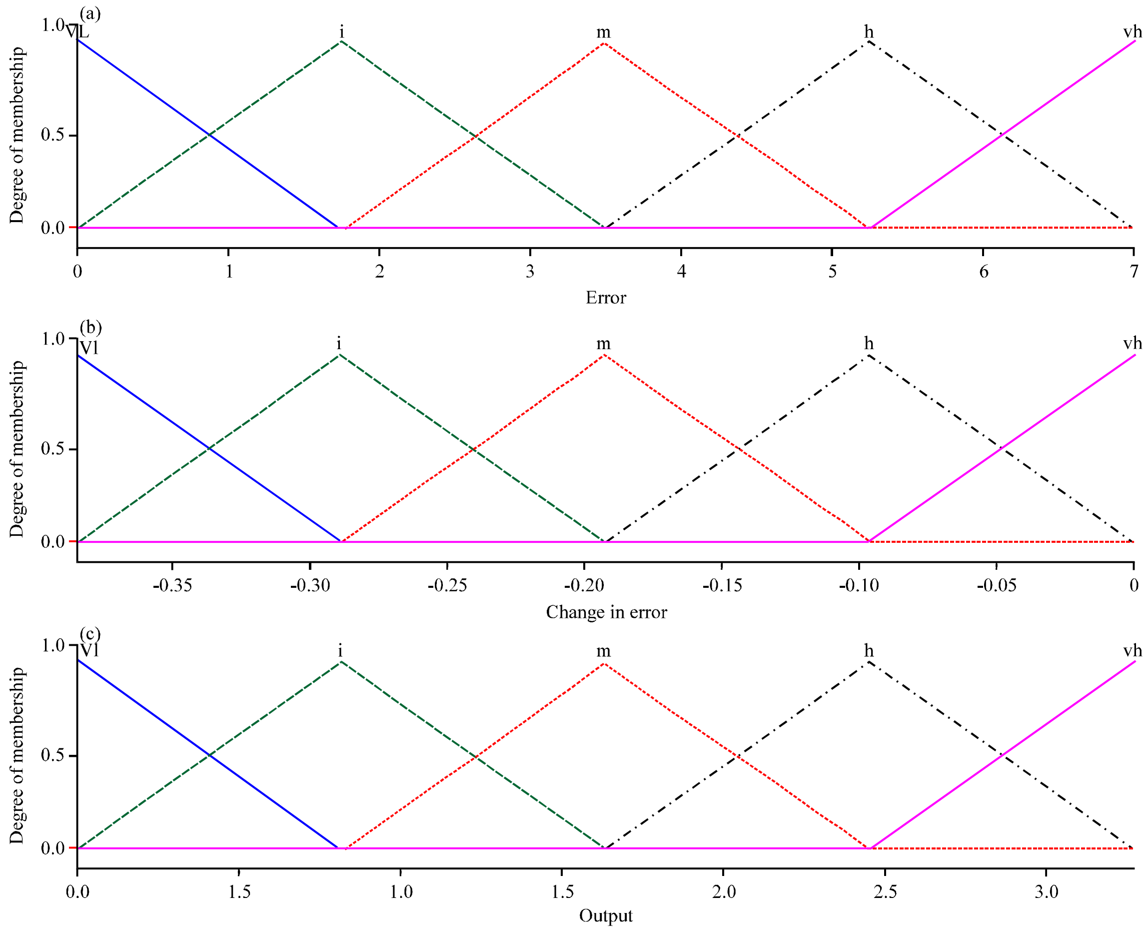

Fig. 3(a-c): Untuned midpoints of membership functions for model 1. (a) Error membership function, (b) Change in error membership function and (c) Output membership function

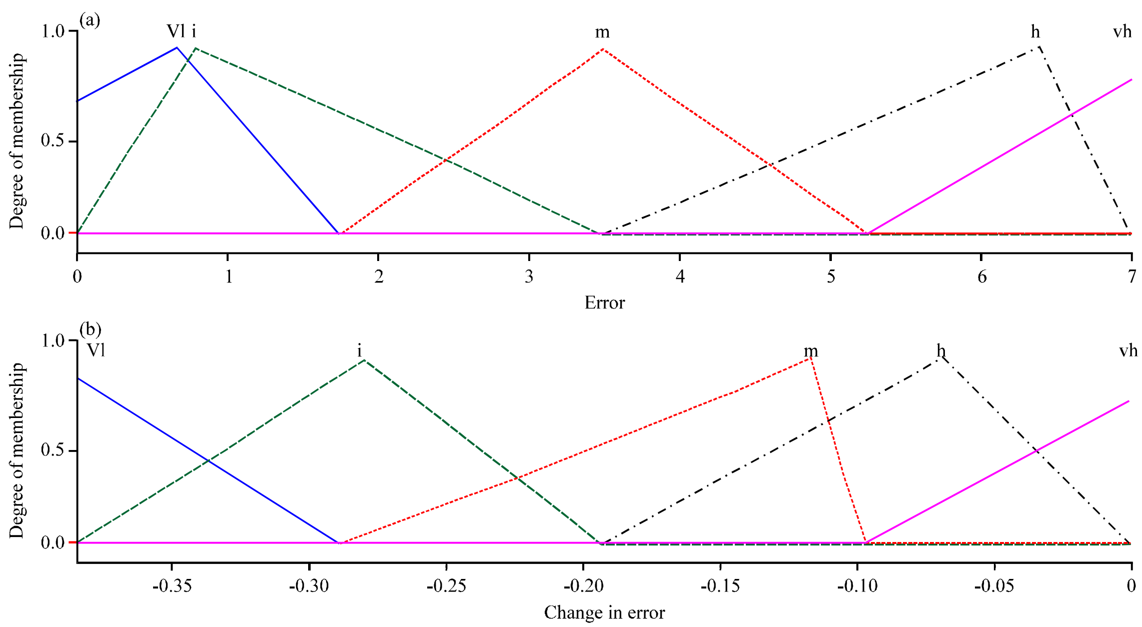

Fig. 4(a-c): Continue

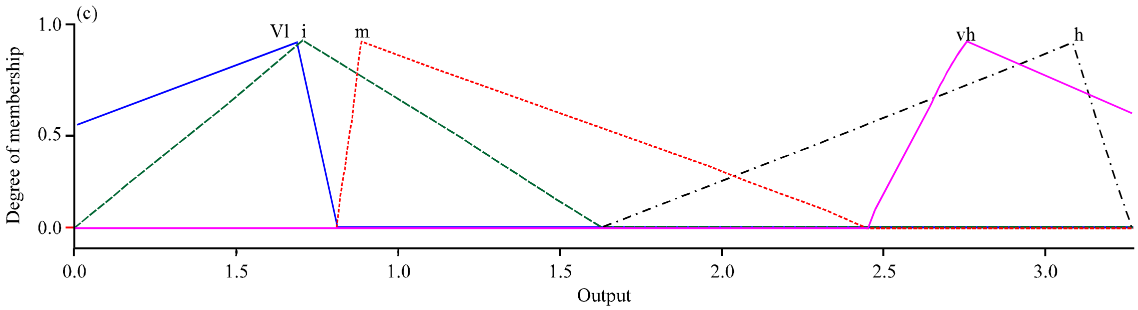

Fig. 4(a-c): Tuned midpoints of membership functions for model 1. (a) Error membership function, (b) Change in error membership function and (c) Output membership function

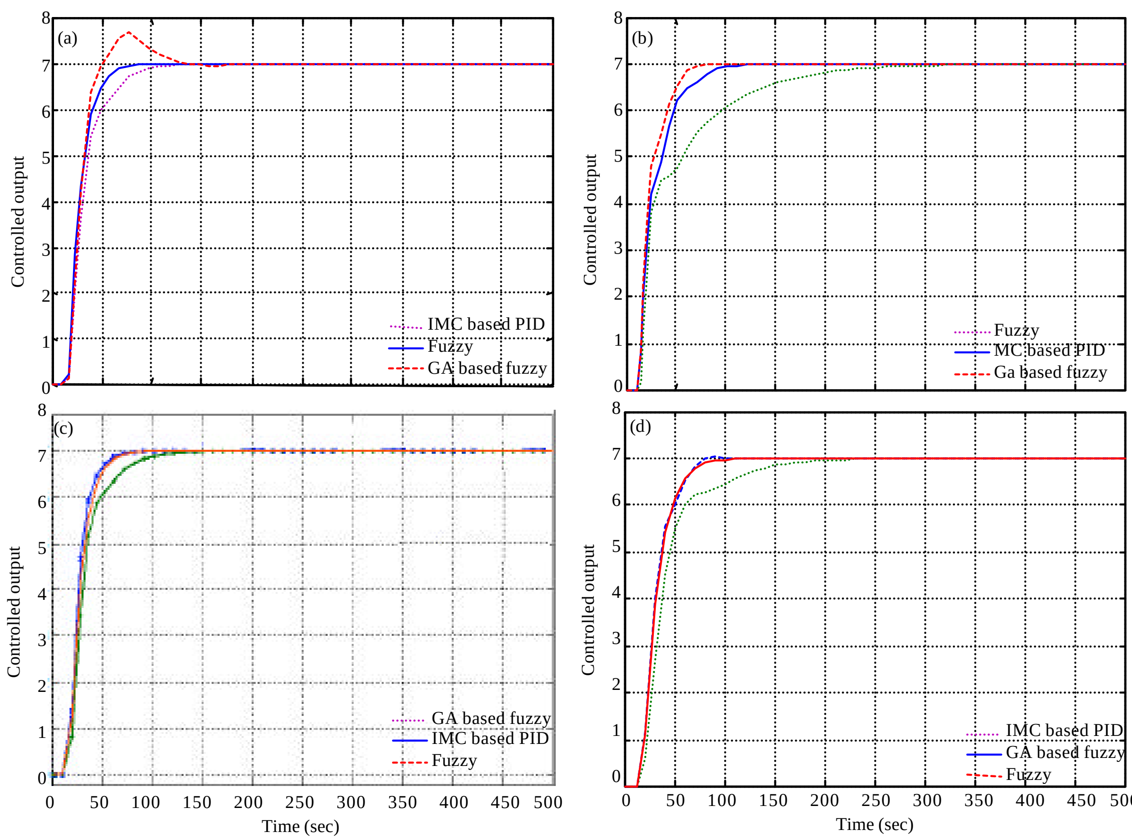

Fig. 5(a-d): Comparison of response between IMC based PID, fuzzy and GA based fuzzy controller. (a) Model 1, (b) Model 2, (c) Model 3 and (d) Model 4

RESULTS AND DISCUSSION

The output response of the GA optimized fuzzy controller is compared with IMC-PID controller for all the four models and is shown in Fig. 5. It can be observed from Fig. 5a for model1 that the IMC based controller gives a sluggish response, on the contrary, though the GA based fuzzy controller gives a much faster response, it gives higher overshoot. For this model, fuzzy based controller gives a better response in terms of overshoot and rise time, but it gives poor settling time performance.

The very slow nature of the behaviour of the IMC based PID controller is quite evident from Fig. 5b for model 2 and it is obvious from the figure that the GA based fuzzy controller gives the minimum overshoot, rise time and settling time in comparison with the other two controllers.

Table 2: Comparison of different controller performance index

Model	Controller	ITAE	ISE	IAE	Rise time (sec)	Settling time (sec)
1	GA based fuzzy	54638.280	3647.985	609.968	20.610	49.94
	Fuzzy	55848.350	3657.426	669.450	20.460	68.63
	IMC based PID	69154.230	3746.389	702.952	40.248	125.05
2	GA based fuzzy	3319.691	2792.637	417.022	33.240	81.48
	Fuzzy	14246.600	2844.668	456.757	40.720	117.50
	IMC based PID	16945.050	2990.555	461.281	100.730	328.40
3	GA based fuzzy	44688.430	1870.026	353.253	27.370	84.92
	Fuzzy	45247.990	1888.966	355.775	29.160	88.74
	IMC based PID	57279.330	3087.417	472.336	41.680	141.12
4	GA based fuzzy	38844.310	1724.770	329.285	38.340	78.39
	Fuzzy	45075.130	1880.180	352.642	35.930	106.36
	IMC based PID	61152.150	3226.313	511.131	60.320	237.30

In Fig. 5c, a rise time of 27.37 sec which is much lesser than the other two controllers and it is visually clear that in terms of overshoot and settling time also GA based fuzzy controller gives a much better performance for model 3.

The linearized fourth model of the nonlinear conical tank when controlled using different controllers shows a better performance for a specific controller and in this case it is the GA based fuzzy controller is shown in Fig. 5d. But the issue is though GA based controller shows minimum overshoot, its rise time is little higher than the fuzzy controller.

The performance index of the controllers for all the four models are shown in Table 2 and it is found that GA based fuzzy controller performs better than the other two controllers with minimal ISE, IAE, ITAE criteria and better transient performance in terms of rise time and settling time.

CONCLUSION

In this study, a GA based fuzzy controller for the level control of conical tank system is presented. Comparison of the proposed controller for different models of the system with IMC based PID controller and the normal fuzzy controller highlights its superiority. For each set point, the proposed controller gives better ISE and IAE values than the other control scheme. From that it is found that the GA optimized fuzzy controller performs very well and thus can be used for nonlinear processes.

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