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PERFORMANCE INDEX BASED COMPARATIVE STUDY AND ANALYSIS OF HIGHLY COMPLEX NONLINEAR DYNAMIC SYSTEM

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ABSTRACT

This paper presents the modification of adaptive neuro fuzzy interference system for interaction problem solving of highly complex nonlinear multiple input multiple output quadruple tank system. one of the problem of the mimo system is interaction which create major issues in industrial process. Major problem of industrial nonlinear process to control and stabilizes the dynamic response of the system. in this research paper gives Conventional PID controller and ANFIS based controller and also a modification of the ANFIS controller (CANFIS) for improving the dynamic response and change the coupling effect. The result of all controller for QTS system, CANFIS controller gives the better control and improve the dymamic response of the highly nonlinear control system. Based on performance criteria give better output than other controller and control and stabilizes the highly complex nonlinear system. ANFIS and CANFIS controller, which is used for nonlinear applications. Finally a comparative study of performance index and analysis between different control strategies is carried out.

KEYWORDS: PID, Nonlinear QTS System, ANFIS, CANFIS.

INTRODUCTION

Control of nonlinear system is major issues in process industries, many significant contributions have been made not only an aspect of explaining and analyzing the dynamic response and improving performance index among the all techniques PID widely used [1]. In the mid 60s fuzzy logic was invented by zadeh for presenting imprecise knowledge and uncertain. In this research work coordination minimize the coupling effect and control of the complex nonlinear system. In the recent year significant research on the field of advance controller design for highly nonlinear mimo system. It gives the idea about approximate but reliable, effective mean of explaining behavior of the certain system that are ill defined very complex or not easily proved through mathematically.

In the fuzzy controller of the given system process by defining the fuzzy variable. In the fuzzy controller involved fuzzification, fuzzy interference and defuzzification [2] in the requirement of the fuzzy modeling two contradictions involves for the strength of the neauro fuzzy system.

The CANFIS control of these papers was simulated in platform MATLAB. A QTS (Quadruple tank system) is a highly interactive system l in which a control level of two bottom tanks ensuring proper achievement level of the tank to achieve a specific output and minimized the effect of the interaction.

The Quadruple tank nonlinear system is a highly complex system. ANFIS and CANFIS controller accuracy of QST system is reflected by the various control techniques and effected parameters of the system. A control techniques are the mathematical expression of the control activity to be evacuated.

For complex nonlinear mathematical modeling the design of the control algorithms very difficult The CANFIS has been demanding to create the system highly stable and give accurate results, but cannot reject the steady state error in the complex system [2] [23]. However, the PID controller is easily calculated and very accurate, and very reliably which nullify the steady state error based on the selection of specific parameters of the controller in the conventional manner. So that, the modification based on CANFIS compares with the conventional controller and the this new developed controller has to take the advantages of both PID and fuzzy controller and ANFIS [1][23]. The Proposed controller is enforced by the quadruple tank system to control the level of bottom tank. And getting desire response of the bottom tanks. The new controller design based on fuzzy

logic and the neural networks (specific characteristics) are two methods for scrutinies which enforced in many practical diligence.

The applications of neural networks in the field of control systems have become increasingly significant based on upcoming technology. The other type of back propagation neural network based on the generalized, a gradient descent search technique, delta learning rule have been used widely for scrutinies of the complex system The various combinations between the two methods (Neuro-fuzzy control systems) is a powerful identification and control technique [3]. These techniques are very useful when the system assumed to be nonlinear system and also system under study, partially unknown [4]. Some of the disadvantage in back propagation algorithm, among which is the lack of guaranteed convergence, but it is a very hefty method based on mathematics had been made of Neuro-computing. Several learning architectures proposed whereby the neural network might be trained [4]. An adaptive network, fuzzy interference system is developed. In this research paper we will introduce two learning program also introduced coactive ANFIS program is implemented in two ways. Modification of ANFIS is called coupling of neuro fuzzy system implimentaed using matlab. Testing of this algorithm with multiple input and multiple output with highly complex quadruple tank system.

MATERIALS AND METHODS (SIMULATION METHOD)
Quadruple Tank System
The process which has nonlinear charecteristics, has a more interaction of quadruple tank processes, which are touchstone processes used in many industries application. This frame up is very simple and rugged but still the system would elaborate concerning multiple variable techniques. The process flow diagram is viewed in Figure 1. The main obeject has to maintaining to the levels Y1 and Y2 at bottom tanks with prime movers. This mathematical model needed for the present practical lab includes and also the disturbing effect of flows in and out of the upper-level tanks. Inputs voltage is applied to prime movers V1 and V2 (input voltages to the pumps).This process is represented by the differential equations according to the material balance equation. Process are represented by equations

$$\frac{dh_1}{dt} = -\frac{a_1}{s_1(h_1)}\sqrt{2g|h_1|} + \frac{a_3}{s_1(h_1)}\sqrt{2g|h_3|} + \frac{\gamma_1 k_1 v_1}{s_1(h_1)}$$

$$\frac{dh_2}{dt} = -\frac{a_2}{s_2(h_2)}\sqrt{2g|h_2|} + \frac{a_4}{s_2(h_2)}\sqrt{2g|h_4|} + \frac{\gamma_2 k_2 v_2}{s_2(h_2)}$$

$$\frac{dh_3}{dt} = -\frac{a_3}{s_3}\sqrt{2g|h_3|} + \frac{(1-\gamma_2)k_2 v_2}{s_3} - \frac{k_{d_1} d_1}{s_3}$$

$$\frac{dh_4}{dt} = -\frac{a_4}{s_4}\sqrt{2g|h_4|} + \frac{(1-\gamma_1)k_1 v_1}{s_4} - \frac{k_{d_2} d_2}{s_4}$$
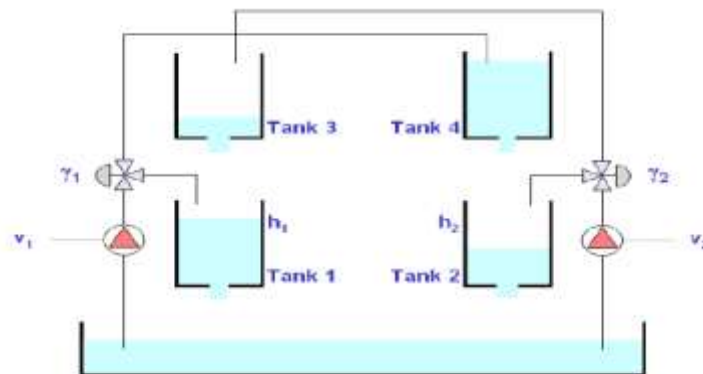

Figure 1: Schematic of the quadruple-tank process

This process presents interacting multiple variable dynamics, complex system because of each of the primemovers involves both of the outputs. This process exhibits nonlinear model and the nonlinear model convert to linearized model of the quadruple-tank process has multi variable zero, which are to be situated in the left or the right half- s plane by adjusting the throttle valves position γ1 and γ2. its showed that the inverse response (non minimum phase) will happen when the value of this valve in the range of $0 < \gamma1 + \gamma2 < 1$ and minimum phase for $1 < \gamma 1 + \gamma2 \leq 2$. The setting of the valve will be given to the overall system entirely dissimilar behavior from a multiple variable control point of view. Immeasurable disturbances can be enforced through forced water out of the main upper tanks and into the main bottom man made space small tank. It has

been exhibited reject interference as well as mention covering point. Using the multiple variable four tank process different aspects of multiple variable control systems can be illustrated. For example:

- Development and analysis of decoupling compensator.
- Development and analysis of state feedback compensator for different locations of the zeros.
- The valve settings effect on the location of the zeros.
- Recognize when a process is easy or not to control
- Design and evaluation of decentralized control.
- Development and analysis of mathematical model based predictive Strategy. Development and analysis of μ-analysis-based H∞ control.
- The locations of the zeros on the process output effect in different input directions

Controller Design
The design method is compared with the various tuning method [10] of PID controller design approaches
1. The Conventional PID controller method
2. The Adaptive neuro fuzzy interference controller and
3. The modified Adpative neuro fuzzy interference (CANFIS) Controller

Controller Tuning
The tuning of controller could be explained as maintaining the variable of the controller so that the system dynamic response is better or response based on the designer. There are numeous performance criteria for controller tuning that may accepted, some of which are considered

- Keep the maximum deviation as minimum as possible
- Decreaeses the integral of errors until the process has settled at its settling positions
- Gaining short settling times
- Performance Criteria

In the process control system, two types of performance criteria are to be satisfied, one is steady state performance criteria and second dynamic performance criteria. Performance criteria based on the closed loop response of the an system are, Overshoot ,Rise time. Settling time , Decay ratio and frequency of oscillation. In the specified characteristics can be used by controller designers as per controller selection and parameter value adjustment. Designer mainly concentrates to minimize overshoot, minimum settling time and other parameter which related to having given system. If consider process is nonlinear, the main characteristics' will be changed from one operating point to another operating point after that specific parameter tuning can produce the desired response at the only single operating point in system. If change operating point in the system change controller tuning. Adaptive controller and self tuning controllers are design required fine tuning for specific application . ANFIS and CANFIS provide best adjustment of controller parameters in the case of changing process dynamics.

Tuning based on integral criteria
The response of the complete closed loop system at t= o until steady state has been achieved can be utilized for the formulation of the dynamic performance criteria. Based on the closed response, these methods minimized the area under error vs. time curve.

Significant of the Tuning methods to minimize the integral of error so that towards address for minimum error integral. Minimize of Integral of error is not possible directly because a very large negative error will be minimum value, so that the absolute error value or square of error value is taken and decrease.

Integral of squared area: $\text{ISE} = \int e^2 \, dt$

Integral absolute error: $\text{IAE} = \int |e(t)| \, dt$

Integral of time multiplied by absolute value of error: $\text{ITAE} = = \int t|e(t)| \, dt$

For the computation purpose the upper limit of the integral may be replaced by settling time(ts)

PID WITH QTS
In the nonlinear quadruple tank system. This nonlinear system is utilized for implementing the modelling of single tank, two tank interacting and non-interacting system. For single tank system flow measuring device Rotameter is utilized for measuring the input flow to the tank no 1. Input flow is given to the tank no 1 by maintaining the valve no 3 positions and comparable level is measured with the help of standard calibrated scale along the length of tank1. Level of liquid in tank is also getting by level transmitter in the range of specific current and voltage. In the Quadruple tank system Two tank non interacting system Tank no 2 and Tank no 3 is utilized to implementing two tank non interacting system by adopting the opening of valve no 2 at desire fixed position. Input flow is indicated through flow measuring device rotameter. Input flow is getting by adopting the opening of valve 4 and corresponding level is measured with the need of calibrated scale along the length of

bottom tank 2.The Level of liquid tank is also indicated by level transmitter, giving its output in the range of specifics of current and voltage . Two tank interacting system Tank1 and tank2 is used to implement the two tank interacting systems by adjusting the opening of valve1 at the set position. Input flow is measured through roatameter1. Input flow is given by adjusting the opening of valve 3 and corresponding level is measured with the help of calibrated scale along the length of tank2. Level of liquid tank is also indicated by level transmitter, giving its output in the range of the particular value of current and voltage.

Simulation model of the QTS with PID controller
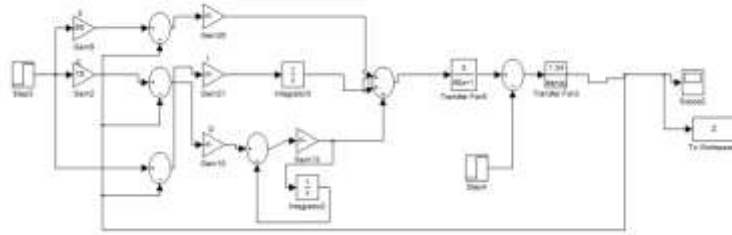
Figure : 2 QTS simulation in Matlab

ANFIS

The technique was developed in the early 1990s. Since it integrates both neural networks and fuzzy logic principles, In the Takagi Sugano fuzzy interference system created by An adaptive neuro-fuzzy inference system (ANFIS). It's one of the artificial neural network based system. A Single Framework has potency to get in both the structure. An approximate nonlinear function learning capability matches to set of fuzzy rules. So that, universal estimator is directed by ANFIS.[4] effective and optimum way to find using ANFIS. Another method could be use the best parameters achieved by artificial intelligent techniques optimization method

ANFIS: Adaptive Network Based Fuzzy Inference System,

Adaptive network prefers that the network having a point and positional connection to the network with supervised learning capacity. In adaptive network having all parts of point, adaptive means output points on the variation of the point. The learning rule is available in different way, it specifies how a particular variable updated to diminish correction. Werbos in 1970s given the gradient descent method relates to network learning rule. Adaptive network every node performs node function this node function varies from point to point.

ANFIS Architecture

In the structure of the ANFIS is two input parameters and one parameter output. In the two rules contain in the rule base. In the architecture of the ANFIS very simple and easy

Rule 1: If B is I1 and C is H1,then f1=d1x+e1y+f1

Rule 2: If B is I2 and C is H2, then f2=d2x+e2y+f2

The Architecture of ANFIS is indicated in the diagram.

The Node function of every layer is explained below:

Layer 1: in this layer every layer has given output with given node function

$$O_i^l = \mu A_i(x)$$

Where, A is the linguistic indication. In this node function O is a membership function of A. X is the input to the node i, in this node function

Bell-shaped Function by

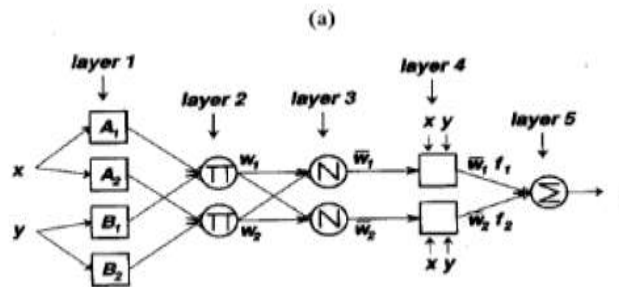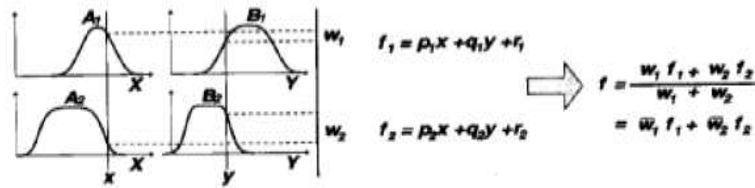$$\mu A(x) = \frac{1}{1 + |\frac{x - ci}{ai}|^{2b}}$$

Figure: 3 ANFIS Model Structure

Here for the node, it can be used trapezoidal and other membership function. Adaptive variable set is of membership function (di; ei; fi) . Given variable, it would be changed and also changed measure of the specific functions and shape of membership functions

Layer 2: for giving layer has each node presents fuzzy AND a method of entering value and raise product output with circle node

$$Wi = \mu Ai(x) \times \mu Bi(y) \quad where \ i = 1,2..$$

Utilized and producing T-norm AND operation in this layer. Here each Fuzzy rule is firing strength

Layer 3: Analyze and evaluate the proportion of ith formules ring intensity with the addition of all rules ring intensity with a specific point.

$$\overline{w_i} = \frac{w_i}{w_1 + w_2} , i = 1, 2.$$

This layer output is called as a normalized ring intensity

Layer 4: each and every point are adaptive points. It is denoted by square point in this level. The point function of this point is

$$O_i^4 = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i)$$

Where pi, qi, ri is adaptive variable and set and this variable is named as consequent parameter.

Layer 5: single node is a circle node for this layer. The node function of this node evaluates the overall output of the network is indicated by,

$$O_1^5 = overall \ putput = \sum \overline{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}$$

The design of the adaptive network is similar to the sugeno type model ad there is no unique network for construction aspect. Establish new network and Layer 3 and 4 are common in the network. In outmost case this network can combine in one node.
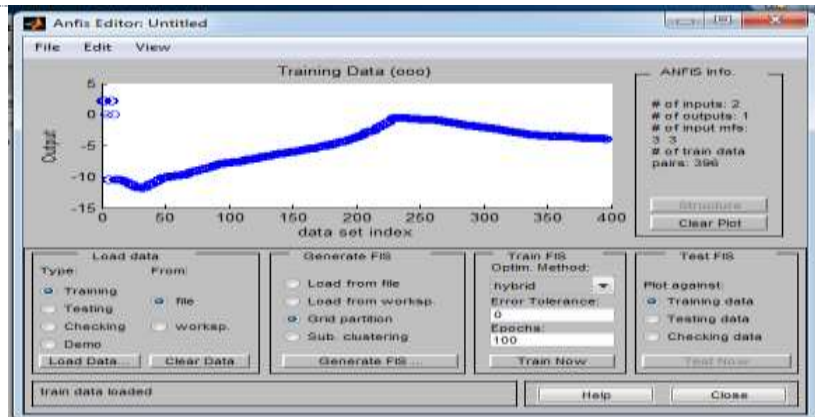
Figure: 4 ANFIS GUI

CANFIS

The neuro-fuzzy modeling and learning mechanisms of CANFIS (coactive neuro-fuzzy inference system) wherein both neural networks and fuzzy systems play active roles together in an endeavor to attain a particular goal. Their mutual dependence presents unexpected learning capabilities. CANFIS has extended the fundamental ideas of its predecessor ANFIS (adaptive network-based fuzzy inference system) The ANFIS concept has been extended to |numerous input-output pairs. Furthermore, CANFIS yields advantages from nonlinear fuzzy rules. In light of some model-related limitations, this proposed method serves to highlight both neuro-fuzzy learning capacities and practical obstacles encountered in performing neuro-fuzzy modeling with Quadruple tank system

Canfis has extended |the thought of single-output system of ANFIS to make multiple outputs. One method to accomplish is to position as much ANFIS models alongside as the amount of required outputs. Each anfis has an unbiased pair of fuzzy rules, rendering it difficult to appreciate possible correlations between outputs. Also the adjustable parameters increases with the escalation in the quantity of outputs

CANFIS has extended the basic concept of its forerunner ANFIS (Adaptive Network based Fuzzy Inference System). In this ANFIS concept has been extended to a variety of input-/output pairs [1]-[5]. In addition, CANFIS yields advantages from non linear fuzzy rules. This CANFIS realizes the sugeno –type (or TSK)fuzzy inferencing accomplishing fuzzy if then rules such as ,If X is A1 and Y is B1, Then C1=p1X+q1Y+r1
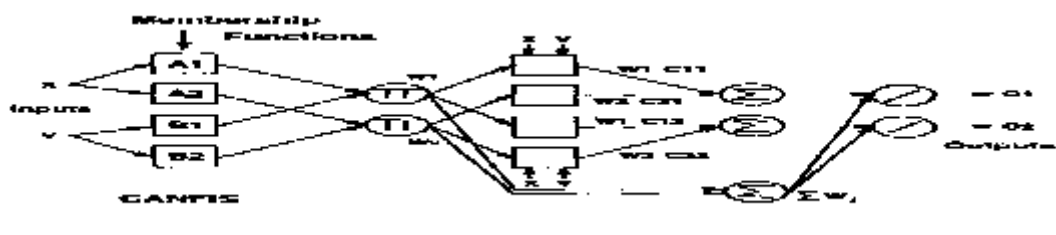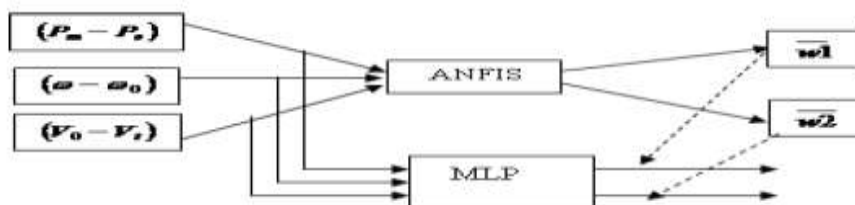

Figure : 5 CANFIS Model

Figure : 6 CANFIS Model Block

Implementation of CANFIS

In this paper, Here discussed using one the strategy for Quadruple tank complex system using ANFIS and CANFIS. This paper has been utilized ANFIS (Adaptive Neuro Fuzzy Inference System) for the MISO (Multi input, single output) system and CANFIS (Coactive Neuro Fuzzy Inference System) has been utilized for MIMO (Multi input Multi output) system. In this paper involved MIT rules used to generate adaption law for MRAC. The ANFIS and the CANFIS tuned has been carried out by tuning rule. MIT rule has been utilized to

manage the nonlinear dynamic mimo system. The comparative analysis between PID, ANFIS and CANFIS has been shown in this paper.

RESULTS AND DISCUSSION
In this paper the rules at Neuro fuzzy system has been introduced membership function generation and its mapping of neural networks is introduced and implemented to control of the highly nonlinear system. The proposed method implements on the quadruple tank system. The result of the proposed techniques is better than Normal ANFIS and a convention PID controller. Using CANFIS Controller, minimize the response based on the performance criteria ISE,IAE and ITAE. The coupling effect of the quadruple tank system also minimize and some better performance can also achieve through proposed techniques The application of Co-active Neuro fuzzy inference system (CANFIS) to predict the output of the quadruple tank system is discussed in this paper. It demonstrated how CANFIS have been used to forecast the response and how it outperforms the ANN model.
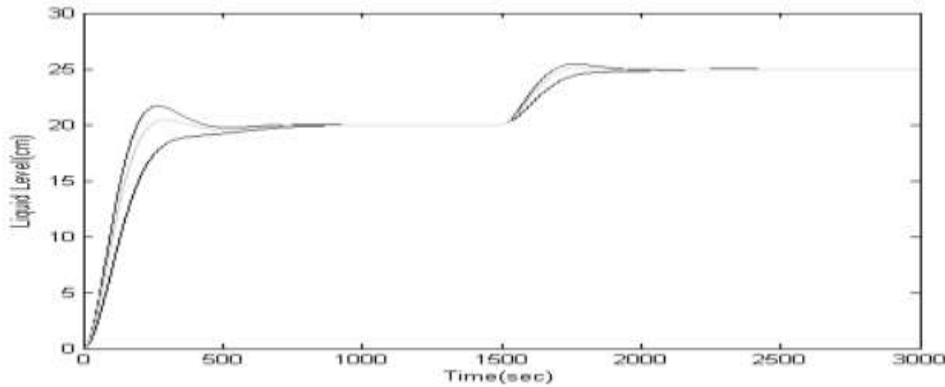

Figure: 5 QTS output response

Comparative Analysis based on the performance index

Operating Point	Controller \Performance index	ISE	IAE	ITAE	Settling time	Rise time	Peak Overshoot
Minimum phase	PID	40	20	10	12	4	0.04
	ANFIS	23	11	4	10	4.5	0.01
	CANFIS	4.5	0.4	2.5	9.5	3.8	0
Non Minimum phase	PID	40	25	10	5	4	0.04
	ANFIS	13	11	4	7	4.5	0.06
	CANFIS	4.5	5	7	9	4.2	0.2

Table: 1 Perfromance index analysis

CONCLUSION
The results confirm that CANFIS offers better performance and better learning capabilities than single Neural network models and the best prediction quality can be achieved by combining the ANN model with Fuzzy logic systems and also conventional PID controller based on 'the performance index ISE, IAE and ITAE. This paper mainly concentrates on searching the optimal controller structure parameter by increasing the controllers' performance criteria. A comparative study of different controllers' method responses is in the full time domain specification. A simulation study of PID controller and ANFIS and CANFIS controller structures have now been designed and to analyze the different controllers' performance for the minimum and non-minimum phase system.

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