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Comparative analysis of Hybridization of Neuro-Fuzzy and Adaptive Neuro Fuzzy for Temperature Control in A Heat Exchanger

Sunil S.Admuthe[1] , Dr.Rajan H.Chile[2] ,Dr.Mrs.Lalita S.Admuthe[3]

[1]Associate Professor, Department of Instrumentation Engg P.V.P.Institute of Technology ,Budhgaon(Sangli), India.

[2] Professor, Department of Instrumentation Engg., S.G.G.S.C.E & T, Nanded , India

[3] Professor, Department of Electronics Engg., DKTE's Textile and Engg. Institute, Ichalkaranji, India

Abstract: To achieve desired temperature is a difficult task, in controlling a temperature of heat exchanger as temperature of liquid changes in different ranges. So an attempt has been made to control temperature of Heat Exchanger by using soft computing methods.This paper features the influence of different controllers like Neuro-Fuzzy and Adaptive Neuro Fuzzy upon the process model of Heat exchanger. Neuro-Fuzzy controller (NFC),which is combination of Neural Network(NN) and Fuzzy Logic Controller(FLC) .Adaptive Neuro-Fuzzy Inference System (ANFIS) is also combination of Neural Network and Fuzzy Logic with adaptive structure. The proposed system is modeled in simulation platform and the output performances are evaluated .The performance has been compared and results show the better superiority for ANFIS.

Keywords: Liquid Heating System, Heat Exchanger, Neuro Fuzzy controller(NFC),Adaptive Neuro Fuzzy Controller (ANFIS),Subtractive clustering, Liquid Temperature , Desire Temperature.

I. INTRODUCTION

Heat exchangers are an essential ingredient in a wide range of industrial applications. Fast tracking of set point change, steady state step disturbance rejections are standard performance requirement for controllers of heat exchanger.

The majority of Heat Exchanger used in Industry [1] operates in closed loop with standard proportional plus integral controllers. Heat exchanger system exhibit different time constants for heating and cooling and non-linear static characteristics

Conventional control theory was based on mathematical models that described the dynamic behavior of process control systems. Fuzzy logic was a flexible approach to conventional controllers. Conventionally, the plants in an industry were controlled by PID controller with Ziegler- Nichols (Z-N) method. The conventional PID controller is not suitable for nonlinear systems [2]. FLC, which were based on human knowledge, were more flexible than conventional PID controllers [3].

Both Fuzzy and Adaptive control algorithms have built in mechanisms that make them well suited for functioning in modern control scenario[4][5]

Since the Procyk and Mamdani self organizing controller [6], many Fuzzy adaptive systems were designed and some practical results were reported [7] [8].Fuzzy adaptive systems provide the advantage that both numerical and qualitative information are used in the construction and training stages. Furthermore Fuzzy systems are proven to be applied to approximate any continuous nonlinear function [8]-[11]

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JyhShing Roger Jang *et.al*. [12] Developed the architecture and learning procedure underlying ANFIS (adaptive neuro fuzzy inference system) which is a fuzzy inference system implemented in the framework of adaptive networks. ANFIS architecture is employed to model nonlinear functions by identifying nonlinear components in a control system

In this paper, both NFC and ANFIS are designed for achieving the desired temperature in the Heat Exchanger.

NFC is hybridization of Neural Network and Fuzzy system. It uses the back propagation algorithm for training neural network and decides structure by trial and error method.

ANFIS also combines the advantages of Neural Network and Fuzzy system .It gives adaptive structure and uses hybrid learning laws which combines back propagation algorithm and least mean square algorithm. Furthermore, to reduce the complexity of a given problem, or to reduce the amount of data associated with a problem first clustering can be done and then Fuzzy Inference System (FIS) is generated. Therefore we tried NFC and ANFIS for controlling the temperature of Heat exchanger.

This paper is organized as follow: Section I gives the introduction of different controlling techniques of heat exchanger and recently available related work. Section II explains the System hardware. Section III contains various controlling techniques. Section IV shows the performance and discussion and last Section V concludes the paper,followed by the references.

II. LIQUID HEATING SYSTEM

The structure of the liquid heating system is illustrated in Fig.1.

The condenser is a device, used for transferring the heat. The condenser consists of two tubes: inner tube and outer tube. The inner tube contains hot liquid, supplied by hot water tank and the outer tube contains cold liquid, supplied by cold liquid tank. The outer tube liquid temperature is controlled by the inner tube liquid of the system. The hot water tank contains heater circuit, stirrer and float type level sensor. The heater circuit consists of Resistance Temperature Detector (RTD), ON/OFF switch and heating coils. The hot liquid tank will continuously supply hot liquid through Automatic Control Valve (ACV), to maintain the heat ratio of the condenser, and which will be controlled by NFC and ANFIS based controller. The exhaust hot liquid is removed. The temperature of the condenser (outer tube) is detected by RTD and given to bridge circuit. The bridge circuit detects the temperature changes and applied to the instrument amplifier. This analog input is converted to digital and applied to the NFC and ANFIS for determining the liquid temperature ratio. The digital output of NFC and ANFIS is converted into analog and further used to control the valve by using pneumatic source.

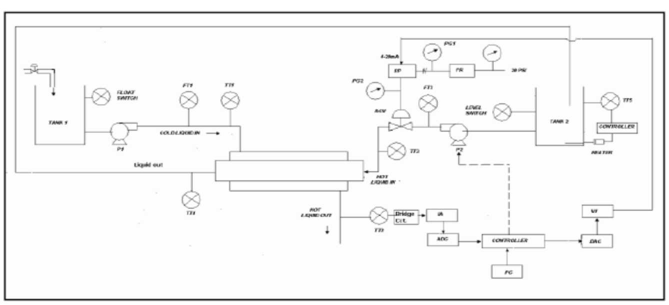

Fig. 1: Structure of Liquid Heating System.

III. DETERMINATION OF LIQUID TEMPERATURE RATIO

NFC and ANFIS are used to calculate the liquid temperature ratio of the system. The ratio of liquid temperature is determined from the current temperature and the change of temperature. The formula for change of temperature is described as follows,

$$Change\ of\ \ Temperature(\Delta T) = T_{desired} - T_{current} \quad (1)$$

Where, $T_{desired}\ and\ T_{current}$ is the desired and current temperature?

3.1 Neuro-Fuzzy Controller:

3.1.1 Determination of Liquid Temperature Ratio Using Fuzzy

The liquid heating system is operated based on multi-variable fuzzy control system. The operation of fuzzy control system is mainly relies on fuzzy rules, which are generated using fuzzy set theory.. The fuzzified error temperature and change of error temperature are applied to the decision making process, which contains a set of rules. Then, the defuzzification process is applied and the liquid temperature ratio is determined. The developed fuzzy rules are tabulated in Table 1. Using these fuzzy rules T_R^F is determined.

Δe \ e	VBP	PB	PM	PS	ZE	NS	NM	NB	VBN
VBP	VBP	VBP	VBP	VBP	VBP	PB	PM	PS	ZE
PB	VBP	VBP	VBP	VBP	PB	PM	PS	ZE	NS
PM	VBP	VBP	VBP	PB	PM	PS	ZE	NS	NM
PS	VBP	VBP	PB	PM	PS	ZE	NS	NM	NB
ZE	VBP	PB	PM	PS	ZE	NS	NM	NB	VBN
NS	PB	PM	PS	ZE	NS	NM	NB	VBN	VBN
NM	PM	PS	ZE	NS	NM	NB	VBN	VBN	VBN
NB	PS	ZE	NS	NM	NB	VBN	VBN	VBN	VBN
VBN	ZE	NS	NM	NB	VBN	VBN	VBN	VBN	VBN

Table 1: Fuzzy Rules for determining liquid temperature ratio T_R^F

3.1.2 Determination of Liquid Temperature Ratio Using NN

These algorithms are operated based on training dataset. From the fuzzy rules, the network training dataset are generated. Feed forward type NN is used for the model. The input layer consist of two inputs i.e., error temperature 'e'and change of error temperature 'Δe'. The liquid temperature ratio 'T_R^{NN}' is the output of the NN.

The training steps involved in neural network are as follows,

Step 1: Initialize the input, output and weight of each neuron. Here, e and Δe are the inputs of the network and the liquid stream ratio 'T_R^{NN}'is the output of the network.

Step 2: The inputs of training dataset are e and Δe to the classifier and determine the BP error as follows,

$$BP_{err} = (T_R^{NN})_{tar} - (T_R^{NN})_{out} \quad (2)$$

In Eq. (2), $(T_R^{NN})_{tar}$ is the target output and $(T_R^{NN})_{out}$ is the network output.

Step 3: Calculate the network output as follows,

$$(T_R^{NN})_{out} = \alpha + \sum_{n=1}^{N} w_{2n1} T_R^{NN}(n) \quad (3)$$

$$\text{Where, } T_R^{NN}(n) = \frac{1}{1+\exp(-w_{1n}e - w_{2n}\Delta e)} \quad (4)$$

Eqn. (3) and (4) represents the activation function of output layer and hidden layer respectively.

Step 4: Adjust the weights of all neurons as $w = w + \Delta w$, where, Δw is the change in weight, which can determined as

$$\Delta w = \gamma . T_R^{NN} . BP_{\text{err}} \quad (5)$$

In Eq. (5), γ is the learning rate, usually it ranges from 0.2 to 0.5.

Step 5: Repeat the process from step 2, until BP error gets minimized to a least value i.e.

$$BP_{\text{err}} < 0.1 . \quad (6)$$

Once the process gets completed, the network is well-trained and it would be suitable for providing T_R^{NN} values for any error and change of error temperature.

3.1.3 Hybridization of FLC and NN output

Hybridization is based on the performance improvement of the process system. The liquid stream ratio 'T_R' of the condenser is calculated for hybridizing the FLC output and NN output. Here, mean operation based hybridization is used for calculating the liquid stream ratio T_R. The mean liquid stream ratio'T_R' is calculated as follows.

$$T_R = \frac{T_R^{dF} + T_R^{NN}}{2} \quad (7)$$

Where, T_R^{dF} is the defuzzified output of FLC and T_R^{NN} is the liquid ratio getting from the NN output. These mean liquid stream ratio'T_R' is applied to the input of the condenser by adjusting the ACV .In this way, the temperature of the liquid heating system is to be maintained.

3.2 Adaptive Neuro Fuzzy Controller-

The liquid heating system is operated based on subtractive clustering and adaptive neuro fuzzy inference system. The operation of adaptive neuro fuzzy control system is mainly relies on fuzzy rules, which are generated using subtractive clustering.

3.2.1 Adaptive Neuro-Fuzzy Inference System

An ANFIS is a multilayer feed-forward adaptive network (Figure 2) in which each node performs a particular function (node function) on incoming signals as well as a set of parameters pertaining to this node. Subtractive clustering is used to generate fuzzy clusters. Each fuzzy cluster is mapped into a generalized predefined membership function. A square node has parameters while a circle node has none. In order to achieve a desired input-output mapping, these parameters are updatedaccording to given data and hybrid learning rule.

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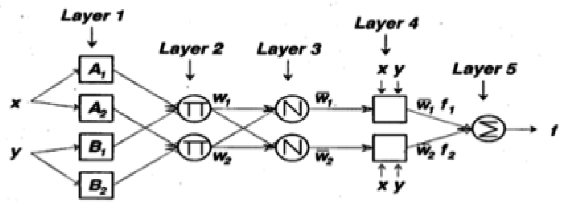

Figure 2 ANFIS Architecture

ANFIS architecture is shown in figure 2, where nodes of the same layer have similar functions. Consider two inputs x and y which form two fuzzy if-then rules

Rule 1: If x is A_1 and y is B_1, then $f_1 = p_1x+q_1y+r_1$

Rule 2: If x is A_2 and y is B_2, then $f_2 = p_2x +q_2y + r_2$ (8)

The output of i^{th} node in layer 1 is denoted as O_{li}

Layer 1 - Every node i in this layer is an adaptive node with node function

$$O_{l,i} = \mu A_i(x) \quad \text{for } i = 1,2 \text{ or}$$
$$O_{l,i} = \mu B_{i-2}(y) \quad \text{for } i = 3,4$$

or B_{i2}) is a linguistic layer associated with the node. Here the membership function for A (or B) can be any parameterized membership function. We have used Gaussian membership function given by

$$\mu_A(x) = \exp[-(\frac{x-c_i}{a_i})^2] \quad (10)$$

Where $\{ci, ai\}$ is the parameter set. These are called premise parameters.

Layer 2: Every node in this layer is a fixed node labeled π, whose output is the product of all the incoming signals.

$$O_{2,i} = w_i = \mu_{A_i}(x) \times \mu_{B_i}(y) \quad i=1,2 \quad (11)$$

Layer 3: Here, the i^{th} node calculates the ratio of the i^{th}rule's firing strength to the sum of all rule's firing strengths.

$$O_{3,i} = \overline{w}_i = \frac{w_i}{w_1 + w_2} \quad i=1,2 \quad (12)$$

Layer 4: Every node i in this layer is an adaptive node with a node function

$$O_{4,i} = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i) \quad (13)$$

Where wi is a normalized firing strength from layer 3 and $\{pi, qi, ri\}$ is the parameter set of the node. These parameters are referred to as consequent parameters.

Layer 5: The single node in this layer is a fixed node labeled ∑, which computes the overall output as the summation of all incoming signals:

$$O_{5,1} = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad (14)$$

In ANFIS, the parameters are associated with given membership function to tailor the input-output dataset. The input membership functions of a Sugeno

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model are non-linear (Gaussian Membership function) whereas the output membership functions are linear. So, while tuning the parameters from a given input/output dataset, it is most effective to use hybrid learning algorithm. Since, the input functions are non-linear, error Back-Propagation method is suitable. As output functions are linear Least Square Estimation method becomes effective.

IV. RESULT AND DISCUSSION

The liquid heating system is simulated in MATLAB working platform version 7.12. The performances of liquid heating system at different temperature variations are analyzed. The developed liquid heating system simulation model is illustrated in Fig.3.

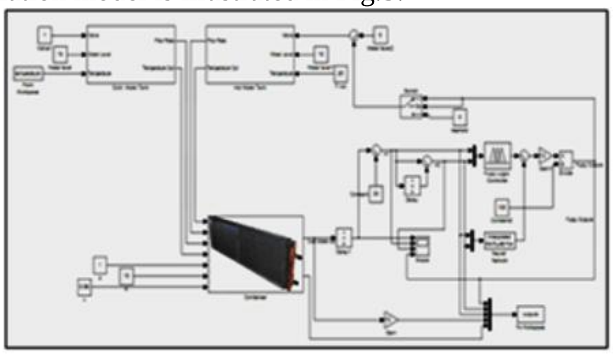

Figure 3: Simulink Model of Liquid Heating System.

4.1 NFC Results

The error and change of error temperature are applied to FLC and the liquid temperature ratio is determined. Surface graph between the error, change in error and predicted output (model output) of NFC is shown in fig.4

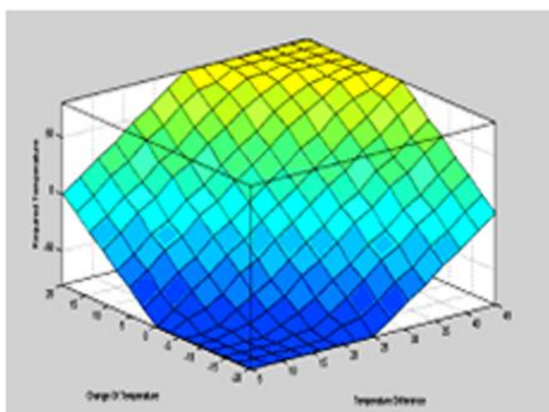

Figure 4: The surface graph of NFC model

The performances of output liquid temperature variation is described in Fig.5

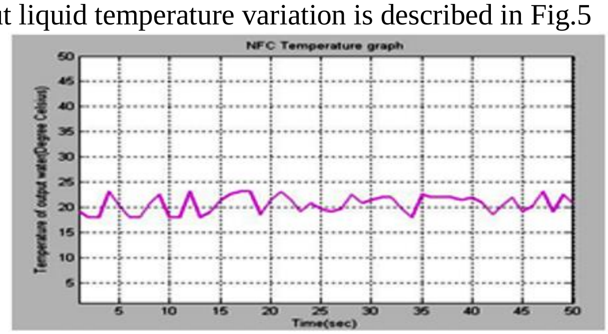

Figure 5: Performance of Output Liquid Temperature of Liquid Heating System after Applying NFC.

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The output liquid temperature variation of the liquid heating system after using the NFC is described below. The performance of liquid temperature ratio from the condenser are described in Fig.6.

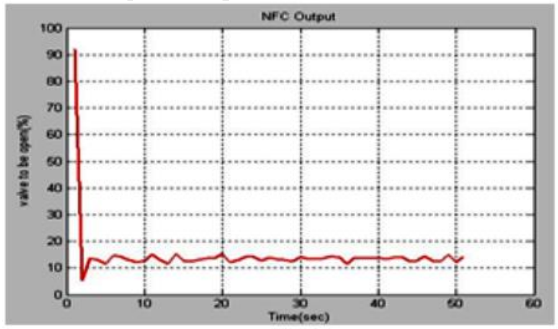

Figure 6: Performance of Liquid Temperature Ratio of NFC.

4.2 ANFIS Results

Error temperature and change in error temperature are the two inputs of ANFIS structure .The membership function of each input was tuned using the hybrid method.

Input dataset is clustered using subtractive clustering before training. The radius used in ANFIS for clustering the data is 0.5. Numbers of epochs assigned are fifty. The ANFIS model is trained by using training data set. Goal for the error is set to 0.05. After training, final configuration for the FIS is generated. Structure of generated FIS is shown in figure 7

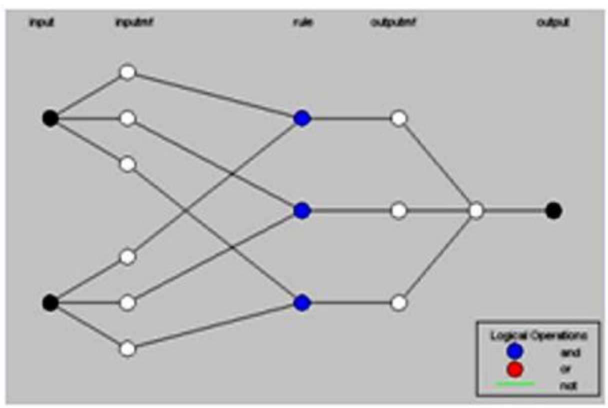

Figure 7: Structure of ANFIS

Surface graph between the error, change in error and predicted output (model output) of ANFIS is shown in figure 8.

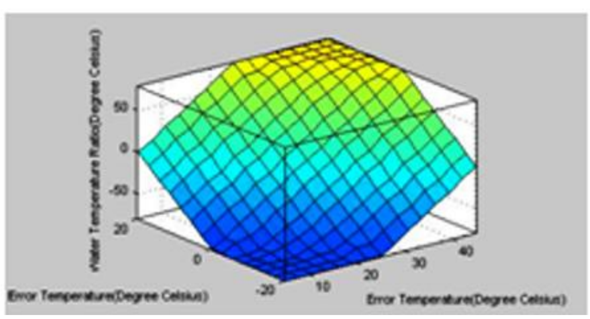

Figure 8: Surface graph of ANFIS model

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The output liquid temperature variation of the liquid heating system after using the ANFIS is described below.

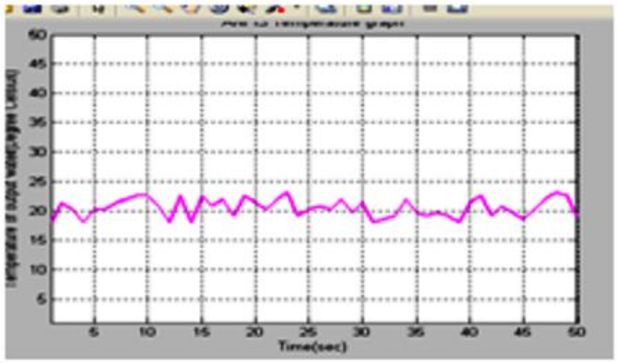

Figure 9: Performance of Output Liquid Temperature of Liquid Heating System after Applying ANFIS.

The performance of liquid temperature ratio from the condenser are described in Fig.10

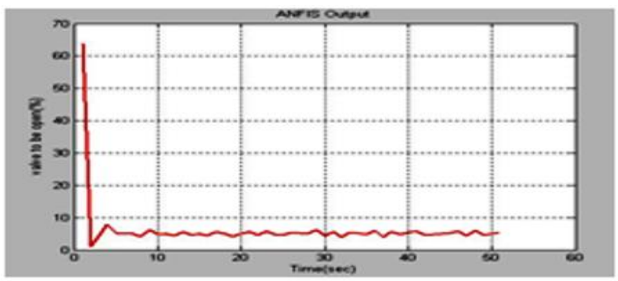

Figure 10: Performance of Liquid Temperature Ratio of ANFIS.

V. CONCLUSION

In this paper, the NFC and ANFIS based model for Heat exchanger system has been designed for maintaining the desired liquid temperature. The model of system is simulated and the output performances are analyzed. The overall performance of both NFC and ANFIS controller is exceptionally accurate. Both need prior analytical information. The ANFIS Performance is slightly better. In addition ANFIS has an adaptive structure therefore no trial and error method is required to decide a structure. The most important point is, it uses different learning algorithms to learn the linear and non linear data. Simulation results have shown that the ANFIS controller has a broader class of nonlinear systems.

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Biography

Sunil Admuthe obtained his Bachelor's degree in Instrumentation Engineering from P.V.P.Institute Of Technology,Budhgaon.Sangli(Shivaji University,Kolhapur .M.S.India). Then he obtained his Master's degree in Instrumentation Engineering from Shri Guru Govind Singhji(S.G.G.S) Institute Of Engineering and Technology.Nanded.(M.S.)India. Since 1989 he is working at various academic positions at P.V.P.Institute Of Technology,Budhgaon,Sangli.(M.S.).India . Currently he is Associate Professor .His specializations include Process control Instrumentation ,Artificial Inteligence,.His current research interests are process automation with Neural N/W , Fuzzy Logic and Adaptive control.

Dr.Rajan Chile Received the B.E .(Instrumentation) and ME(Instrumentation) degrees in 1987 and 1992 respectively from Shri Guru Govind Singhji(S.G.G.S) Institute Of Engineering and Technology.Nanded.(M.S.)India. He had completed his Ph.D from Indian Institute Of Technology(I.I.T.) Roorkee .India in 1999. He is working as Professor in Instrumentation Engineering Department of SGGS Institute Of Engineering and Technology,Nanded.(M.S.)India. His main fields of interest are adaptive control ,process instrumentation,artificial inteligence and Digital Signal Processing (DSP).

Dr.L. S. Admuthe received M.E. and Ph. D. degree in Electronics Engineering from Shivaji UniversityKolhapur, India and currently working as a professor in Electronics engineering department. Her research interests include Fuzzy, ANN, Genetic algorithms and various Clustering algorithms.