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Modelling and Temperature Control of Heat Exchanger process

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Abstract*—The main purpose of a heat exchanger system is to transfer heat from a hot fluid to a cooler fluid, so temperature control of outlet fluid is of prime importance. In this paper, firstly simplified mathematical model for heat exchanger process has been developed and used for the dynamic analysis and control design. Artificial neural networks (ANN) are effective in modeling of non linear multi variables so modeling of heat exchanger process is accomplished using optimized architecture of artificial neural network after that different controllers such as PID controller, feedback plus feed-forward controller and a ratio controller are developed to control the outlet temperature of a shell and tube heat exchanger. The main aim of the proposed controllers is to regulate the temperature of the outgoing fluid to a desired level in the minimum possible time irrespective of load and process disturbances and nonlinearity. The developed ratio controller has improve the overshoot from 1.34 to 0 % and settling time from 148 to 91.8 second over the feed-forward plus feedback controller.

Keywords* – *Artificial neural network, Feed-forward plus feedback controller, Levenberg-Marquardt algorithm, PID controller, Shell and tube heat exchanger

I. INTRODUCTION

efficiency, the heat exchangers are commonly used in the industries such as gas processing, petrochemical industries etc. In this work shell and tube heat exchanger is used for heating or cooling of process fluids. It consists of parallel tubes enclosed in a shell. Basically they are used for high pressure applications (with pressures greater than 30 bar and temperatures greater than 260°C). But the main problem of

To exchange heat among the two fluids with of the different temperatures and with higher

heat exchanger process is the temperature deviation from the desired set point.

Modeling of heat exchanger process for the estimation of hot and cold fluid outlet temperature as a function of flow rates and inlet temperature is accomplished using optimized architecture of artificial neural network. An algorithm that trains

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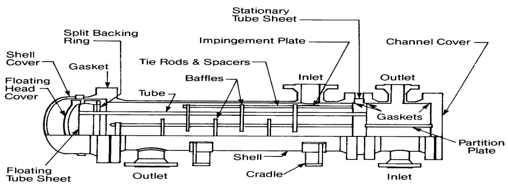

neural network 10 to 100 times faster than the usual back propagation algorithm is the Levenberg-Marquardt algorithm. output are presented to the network, in order for the network to update its weights. The various parameters to be taken into account for developing a model are inlet and outlet temperatures of shell and tube side fluids and their flow rates. Artificial neural networks (ANN) are effective in modeling of non linear multi variables relationship and also referred as the black box models.

First of all, a classical PID controller is implemented in a feedback control loop so as to obtain the control objectives. To further optimize the control performance, feed-forward controller and ratio controller is used in conjunction with the PID controller. Auto-tuning of PID controllers is also implemented and simulated in this paper. A comparative study of all the control performance is evaluated in this paper.

II. MODELING OF HEAT EXCHANGER

Artificial neural network model is developed using optimized architecture for modeling of heat exchanger for estimation of hot and cold fluid outlet temperature as a function of flow rates and inlet temperature. The data required for these networks has been generated using water 20% glycerin case. Following different modes are used to generate data experimentally.

While back propagation is a steepest descent algorithm, the Levenberg-Marquardt algorithm is a variation of Newton's method. The Levenberg-Marquardt algorithm provides a nice compromise between the speed of Gauss Newton and the guaranteed convergence of steepest descent. In this training algorithm supervised learning has been employed where the target values for the

TABLE I

MODES OF DATA GENERATION

Mode	Tube side inlet temperature	Tube side flow rate	Shell side inlet temperature	Shell side flow rate
1	Varied	Constant	Constant	Constant
2	Constant	Varied	Constant	Constant
3	Constant	Constant	Varied	Constant
4	Constant	Constant	Constant	Varied

In this model of actual temperature versus predicted temperature, the actual heat exchanger data using ‘nftool’ of MATLAB was used to train the neural network model. The system automatically takes 60% of data for training, 20% for validation and 20% for testing, so that the same data will not be used for testing. It requires many runs to converge or to get expected training. Once the system was trained then it takes with remaining samples of data for testing. To identify a first order plus dead model (FOPDT) parameters two times are measured: t_1, the time when the output reaches 28.3% of the final change in the steady-state value $Y_F - Y_I$, and t_2, when

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the output reaches 63.2 % of $Y_F - Y_I$. From figure 1, t_1 = 27.792 and t_2 =36.168. By applying the identification process on the above figure obtained the first order plus dead time model (FOPDT) as

$$G_p(s) = \frac{e^{-23.6s}}{12.56s+1} \quad (1)$$

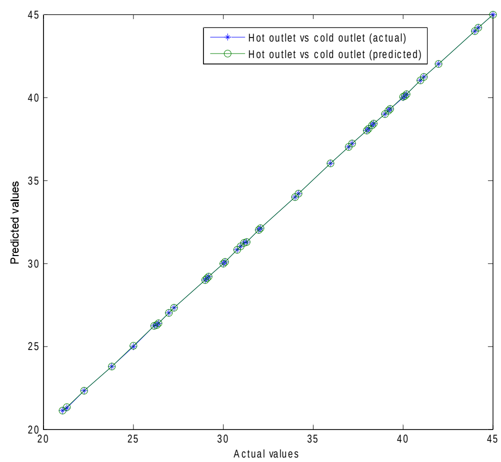

Fig 1: Actual and predicted values of hot fluid and cold fluid

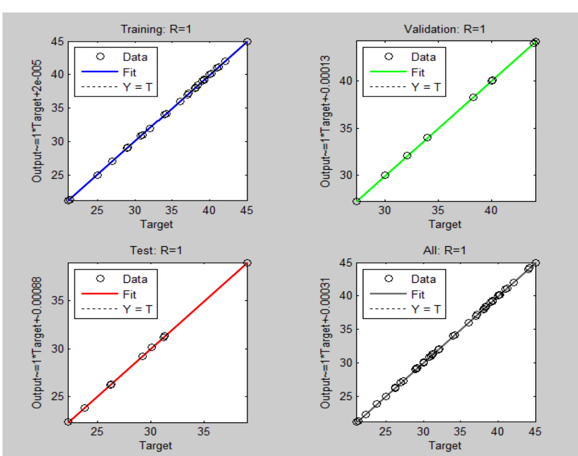

Fig 2: Regression plots for actual and predicted results by feed-forward neural network model for training, validation, testing samples and all data set

In figure 2 the dashed line is the perfect fit line where outputs and targets are equal to each other. The circles are the data points and coloured line represents the best fit between outputs and targets. Here it is important to note that circles gather across the dashed line, so our outputs are not far from targets. From the graph, it can be realized that the best hidden unit with 99% accuracy is with just one neuron with one trial for this model.

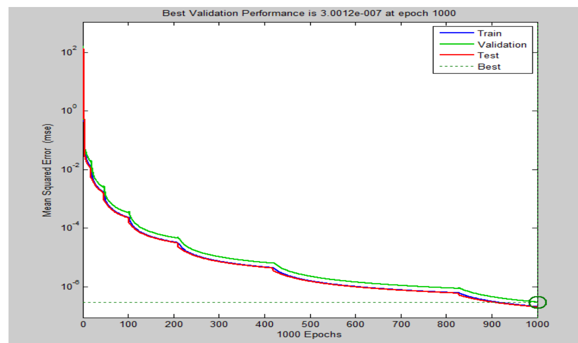

Fig 3: Shows training, validation and testing mean square errors for Levenberg-Marquardt algorithm with one neuron.

Figure 3 depicts the training, validation and test mean square errors for Levenberg-Marquardt algorithm with one hidden neurons. The training stops when MSE do not change significantly.

TABLE II

OPERATING CONDITION

Parameter	Units	Shell side	Tube side
Fluid	-	Water	20% glycerin
Temperature (range)	$^{\circ}C$	39-51	17-28
Flow rates	LPH	57.6-2250	57.6-2250
Specific heat	J/kgK	4184	3406
Viscosity	Ns/m	0.72×10^{-3}	1.447×10^{-3}
Thermal conductivity	W/m^2K	0.66	1.455

TABLE III

PERFORMANCE EVALUATION OF TRAINING, VALIDATION AND TESTING

Number of Hidden Neurons	Operation	Samples	MSE	R
1	Training	27	2.1026e-7	9.99999e-1
1	Validation	9	3.0011e-7	9.99999e-1
1	Testing	9	2.0335e-7	9.99999e-1
2	Training	27	1.5719e-8	9.99999e-1
2	Validation	9	7.8179e-8	9.99999e-1
2	Testing	9	5.6004e-8	9.99999e-1

III. PROBLEM STATEMENT

In this section we have developed a block diagram of these control loops and modeled the heat exchanger system, actuator, valve, sensor using the experimental data available.

The transfer function model of the individual systems are generated which in turn combined to acquire the transfer function of the whole system.

From the above experimental data the transfer function model of the system is derived.

Transfer function of process $G_p(s) = \dfrac{e^{-23.6s}}{12.56s+1}$

Gain of valve 0.133

Transfer function of valve $\dfrac{0.133}{3s+1}$

Gain of I/P converter is 0.75

Transfer function of thermocouple is $\dfrac{0.16}{10s+1}$

A. PID Controller

The characteristic equation (1+G(s)*H(s) =0) in this case is obtained as below.

$$900s^3 + 420s^2 + 43s + 1.78 = 0$$

The PID controller is traditionally suitable for second and lower order systems. It can also be used for higher order plants with dominant second order behavior. A PID controller is tuned according to a table based on the process response test. According to Zeigler-Nichols frequency response tuning criteria

$$K_p = 0.6K_c \quad \tau_i = 0.5T \quad \tau_d = 0.125T$$

For the PID controller in the heat exchanger, the values of tuning parameters obtained are

$$K_p = 0.2781 \quad \tau_i = 10.2 \quad \tau_d = 2.55 \quad \text{and} \quad P = 0.4636$$

$$I = 0.045 \quad D = 1.18$$

Figure 4 clearly shows that the delay will affect the step response of process till the time 23.6 sec. and after that it follow the step response.

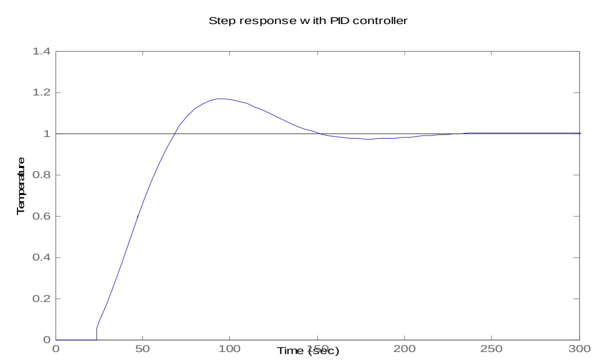

Fig 4: PID controller response

Now different values of K_p i.e. 0.2781 and 0.4636 are used and variation in step response is shown in Figure 4.

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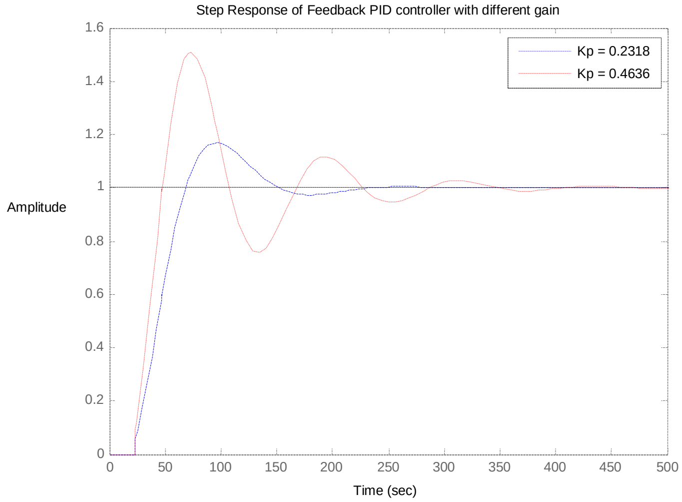

Fig 5: Feedback PID controller with different gains

B. *Feedback and Feed-forward Controller*

A feed forward control estimates the error and changes the manipulating variable before the disturbance can affect the output. To further minimize the overshoot a feed-forward controller is introduced in the forward path of the process along with the feedback controller. The combined effect of feedback and feed-forward controller reduces the overshoot value.

In feed forward controller we have tried to regulate the flow disturbance of the input fluid. $G_p(s)$ is the transfer function of the process where as $G_d(s)$ is the transfer function of flow disturbance.

$$G_p(s) = \frac{e^{-23.6}}{12.56s+1}$$

$$G_d(s) = \frac{e^{-35s}}{25s+1}$$

Gain of valve is 0.133

Transfer function of valve $\frac{0.133}{3s+1}$

Transfer function of thermocouple $\frac{0.16}{10s+1}$

Gain of I/P converter is 0.75

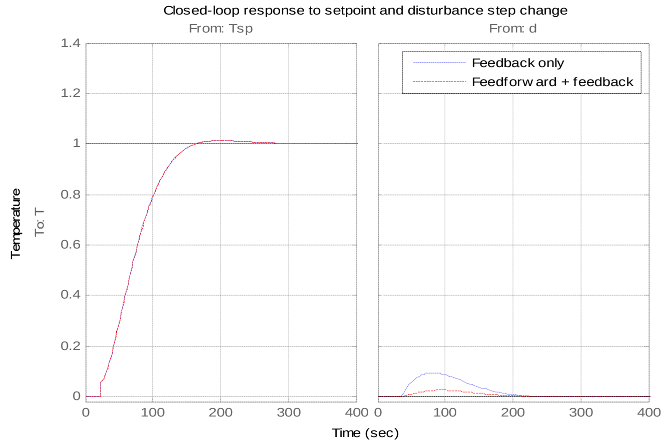

Figure 5: Feed-forward plus feedback controller response

From figure 5, it is clear that feed-forward plus feedback controller provides much faster response as compared to PID controller. Also feed-forward plus feedback controller rejects the disturbance earlier as compared to PID controller. Overshoot and settling time are less as compared to PID controller.

A. Comparison of different Parameters in controllers

TABLE III

COMPARISON OF DIFFERENT PARAMETERS IN CONTROLLERS

Parameter	PID Controller	FB + FF Controller
Rise time	35.95	87.9
Settling time	198.5	148
Overshoot	16.77	1.34

Peak	1.16	1.01
Peak time	97.10	200

C. CONCLUSION

To efficiently control the temperature, designed three kinds of controllers and the modeling of heat exchanger is done using artificial neural network, it can be concluded that the ANN heat exchanger model using Levenberg marquardt algorithm for 20% glycerin has been successful and has very good accuracy level (99% - 99.5%). A classical PID controller is designed to achieve the control objective. But due to the unsatisfactory performance of the PID controller a feed-forward controller is designed and placed in the forward path of the system. It is observed that feed-forward plus feedback controller gives a much better response than any other conventional PID controller.

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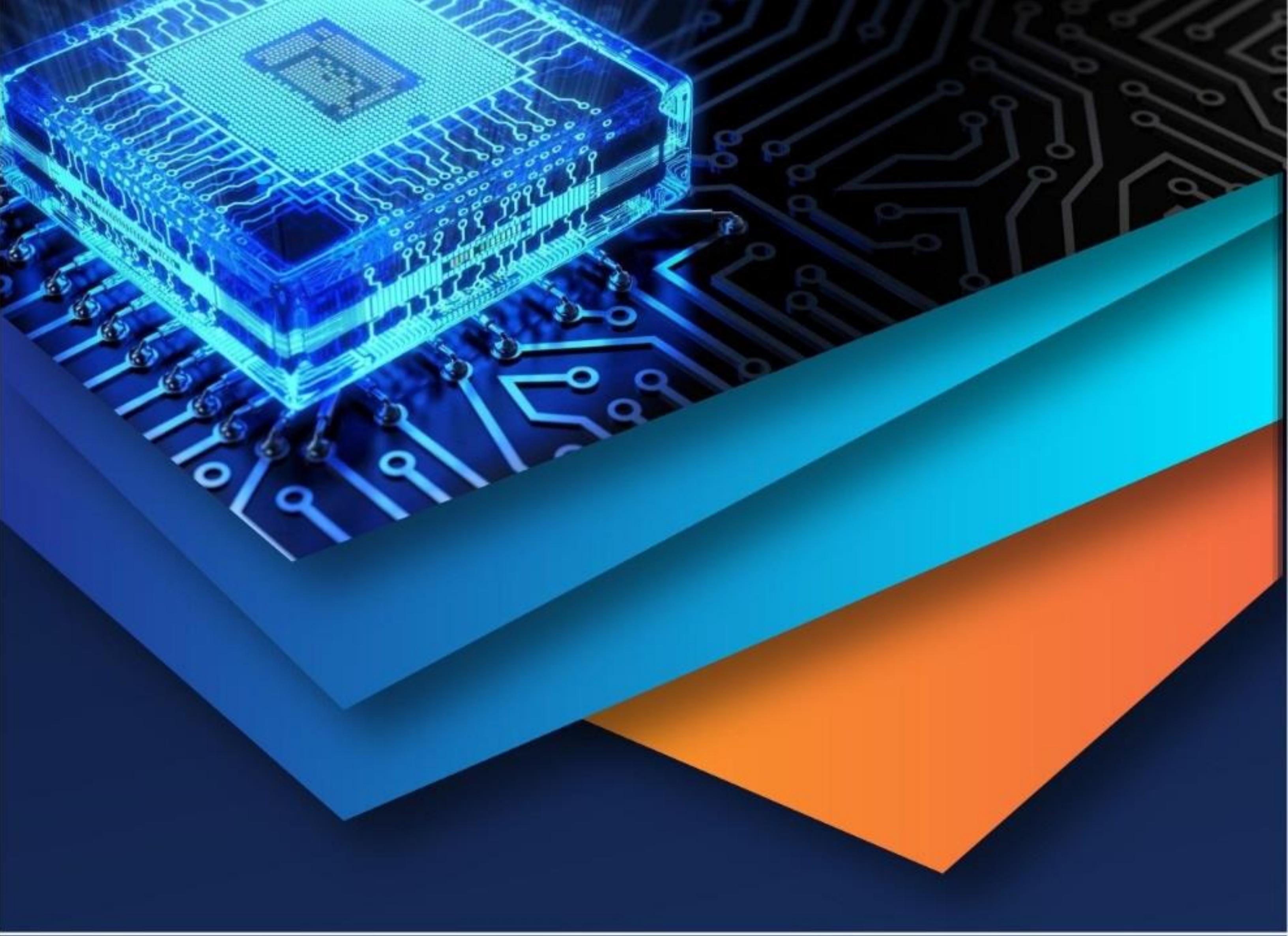

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