Automation of Heat Exchanger using Neural Network

Sudhir Agashe, Ashok Ghatol, and Sujata Agashe

Abstract—In this paper the development of a heat exchanger as a pilot plant for educational purpose is discussed and the use of neural network for controlling the process is being presented. The aim of the study is to highlight the need of a specific Pseudo Random Binary Sequence (PRBS) to excite a process under control. As the neural network is a data driven technique, the method for data generation plays an important role. In light of this a careful experimentation procedure for data generation was crucial task. Heat exchange is a complex process, which has a capacity and a time lag as process elements. The proposed system is a typical pipe-in- pipe type heat exchanger. The complexity of the system demands careful selection, proper installation and commissioning. The temperature, flow, and pressure sensors play a vital role in the control performance. The final control element used is a pneumatically operated control valve. While carrying out the experimentation on heat exchanger a well-drafted procedure is followed giving utmost attention towards safety of the system. The results obtained are encouraging and revealing the fact that if the process details are known completely as far as process parameters are concerned and utilities are well stabilized then feedback systems are suitable, whereas neural network control paradigm is useful for the processes with nonlinearity and less knowledge about process. The implementation of NN control reinforces the concepts of process control and NN control paradigm. The result also underlined the importance of excitation signal typically for that process. Data acquisition, processing, and presentation in a typical format are the most important parameters while validating the results.

Keywords—Process identification, neural network, heat exchanger.

I. INTRODUCTION

THE use of neural network for control is not a new idea for the researchers. Process identification through decision theory was successfully implemented in 1964[1], using only input output relationship rather a detailed structure of the process. The work carried out till date by most of the researchers, was focused on implementing NN control for a

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where complexities are not defined. NN control is normally used as the black box approach, wherein the knowledge of the process is not required to be known. The approach adopted in this paper is to have detailed knowledge of the process, and then implement neural network. This enables to check the accuracy of process identification and further comment on the usefulness of NN, in process control [2].

Many attempts are made till date to make process control effective irrespective of plant surges [3], demand fluctuations, and utilities misbehaviour. The major thrust of researchers is on making process control operator independent, and control system component friendly. The techniques used to achieve this dream include use of mathematical modeling, optimaisation of resources, and rugged system design. Use of Artificial Intelligence is increasing day by day because of it's adaptability to changes, and ruggedness in control [4]. Many process experts are using process identification techniques and modeling tools to simulate the behaviour of the process, and obtain the judgment for the operating region of the process.

The study carried out is reported in three sections viz. pilot plant development, experiments carried out to test the existing techniques for process control, use of neural network for process control.

II. PILOT PLANT DEVELOPMENT

The main aim for developing the pilot plant is:

i. Develop state of art experimental set-up/pilot plants, which will be vibrant enough to get excited to its extreme limit without compromising the safety standards.

ii. Develop a mechanism to collect the data and convert it in the form acceptable to most of the process analysis and statistical tools.

iii. Develop an algorithm, which will initially excite the system to obtain operating region of the process, then generate a pseudo random excitation signal and generate enough data to obtain reliable and accurate function approximation.

The pipe in pipe type heat exchanger was developed as pilot plant for study [6]. The heat exchanger designed in the laboratory is recuperative type, counter flow, double pipe type. This pipe in pipe type heat exchanger using the steam produced by an electrically fired boiler raises water temperature. To avoid formation of scale and reduce

maintenance treated water is used. Heat released by operating heaters is utilized for heating water in the shell. Insulation of shell is done with glass wool to prevent heat losses. The steam pressure is controlled by means of a pressure switch at 4.5 Kg/cm^2.

A PT-100 sensor monitors the temperature at the inlet and outlet water. The inlet water flow is measured with a magnetic flow meter, while the steam pressure is monitored using HART based pressure transmitter. All the sensors are interfaced to a Distributed Control System (DCS). The sensors, transmitters, converters, and control valves are initially calibrated before commissioning. The control valve sizing is based on the operating process data, and valve selection is based on the process conditions. The mimic of the plant is as shown in Fig. 1.
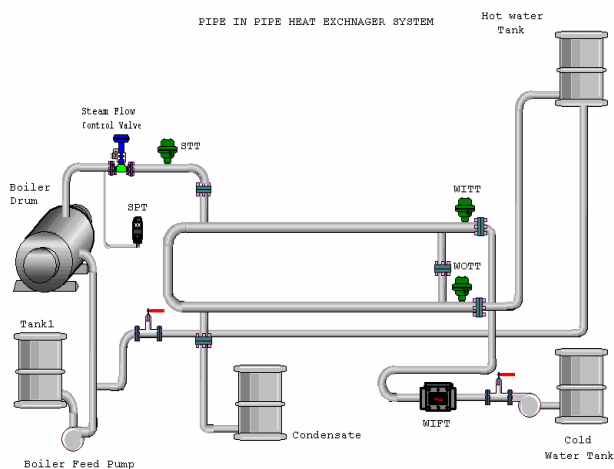

Fig. 1 Mimic diagram of heat exchanger pilot plant

The disturbances for this process are inlet water flow, inlet water temperature, and steam pressure. Modelling of these disturbances is very critical, as they do not posses any linear relation. The nomenclatures used for representing various process parameters are:

STT: Steam Temperature Transmitter
SPT: Steam Pressure Transmitter
WITT: Water Inlet Temperature Transmitter
WOTT: Water Outlet Temperature Transmitter
WOFT: Water Outlet Flow Transmitter

III. EXPERIMENTATION

The main thrust of this experimentation is on accurately and consistently capturing the data, converting it in the form suitable for the tool. While performing the experimentation utmost care has already been taken as regards to safety aspects, and interlocks. A well laid-down procedure is being followed for experimentation. The success of the NN control depends on the data provided for training, testing, and validation. The process needs to be excited so as to obtain the total dynamics of the process. Many experiments were

conducted to obtain the faithful response of the process. The excitation signal should deliver as much input power to the system as possible. However, in the real world, ensure that this input power stays within the limits of the physical system. The crest factor represents the exactness of the excitation signal. The smaller crest factor the better the signal excitation resulting in larger total energy delivery and enhanced signal-to-noise ratio. The theoretical lower bound for crest factor is 1. To obtain the response, system is excited using varying amplitude and frequency signals [5]. Following experiments are conducted for obtaining the operating region of the process, response to various ramp signals, and useful Pseudo Random Binary Signal (PRBS) for this particular system.

A. EXPERIMENT NO. 1: Test the response of the system for various ramp rate signals.

In this experiment a ramp signal is applied to steam valve of heat exchanger using RAMP block of Delta-V DCS. The results are as shown in Fig. 2.
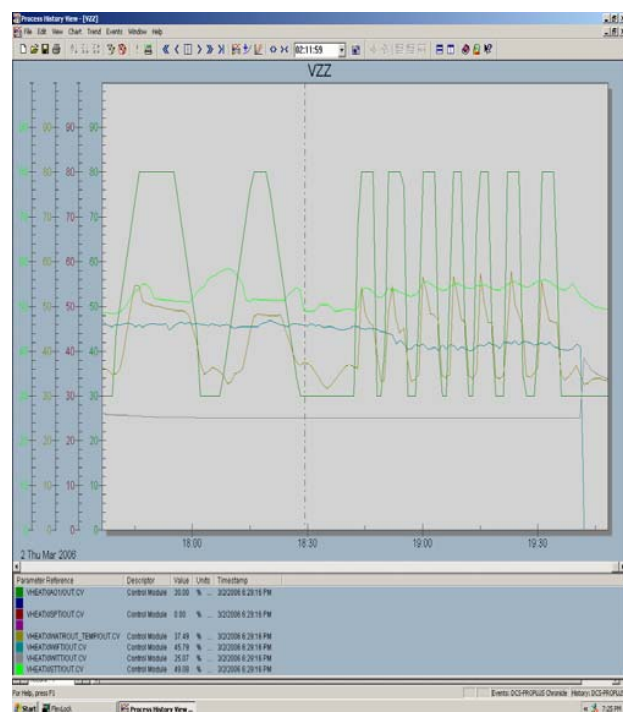

Fig. 2 Response of system for various ramp rates

After careful study of the response, it is observed that if the valve is opened up-to 80% there is an overshoot in the steam temperature, which affects the controlled variable.

Instead of using a various ramp rate signals, the PRBS readily available with the control system was used for exciting the process.

Experiment No. 2: Study of response of the system to PRBS signal.

The frequency at which the PRBS signal is designed in the DCS is not adequate for exciting the process. Hence it is clearly being seen in the graph that the process does not respond to the fast changing signal. This is because of the

sluggish response of the pneumatically operated diaphragm control valve. For some portion of the PRBS the process responds, but this excitation do not give the entire spectrum of the dynamics of the process. The dead time calculated and confirmed through experimentation is 7 seconds; hence the accounting of this dead time is essential while exciting the system.

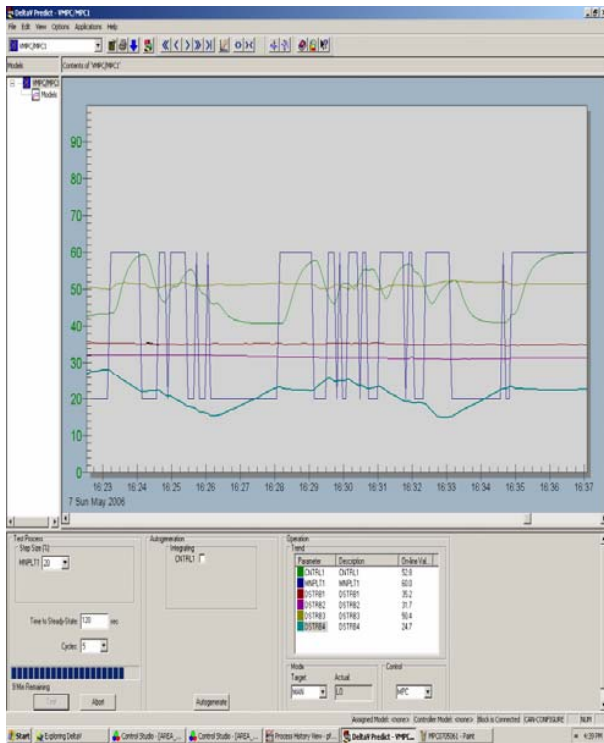The process was excited using the PRBS signal. The response obtained is represented in Fig. 3.

Fig. 3 PRBS signal response of the process

Experiment No. 3: Response of the system to manually generated random signal:

As seen in the previous experiment the process does not respond to the PRBS available, the signal needs to be manually generated like PRBS, with frequency component suitable for the process. The response of the system can be seen in fig. 4. The nature of the response clearly indicates that in certain region of operation the process behaves as per our expectations. While in some areas the steam pressure drops because of more opening of the control valve, so suddenly that the regaining of the pressure becomes very difficult. This fact is because of the capacity problem of the boiler. Once the boiler is commissioned it is utmost essential to use the systems as they are. Hence the identification of operating region for the experimentation is carried out. The operating region can be defined as that region of the process where the utilities are stable and wide range of controllability can be achieved. In this experiment it was also observed that the traditional control paradigms are not sufficient to control the process, as the disturbances outside the loop are aggressive, in this case

steam pressure. The response clearly shows that the steam pressure variation is a dominant parameter and hence plays a vital role in process identification and control. The steam pressure is outside the limits of normal process control paradigm. The traditional controller treats this as a disturbance and control of outlet water temperature fluctuates within the band of 3%.
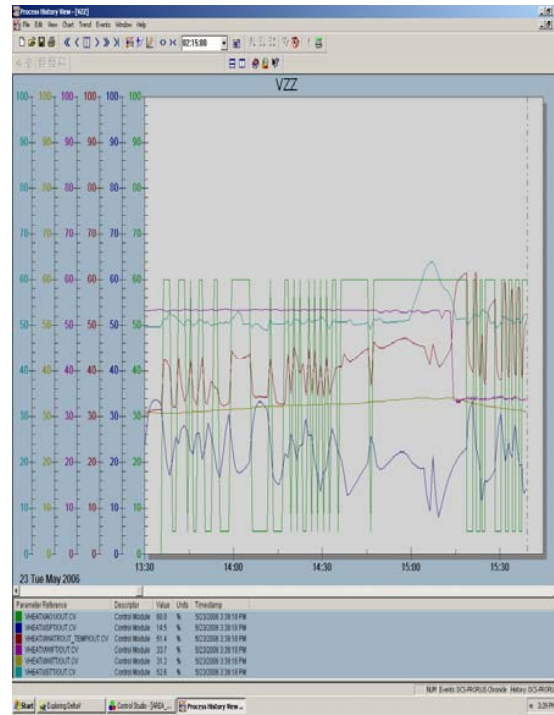

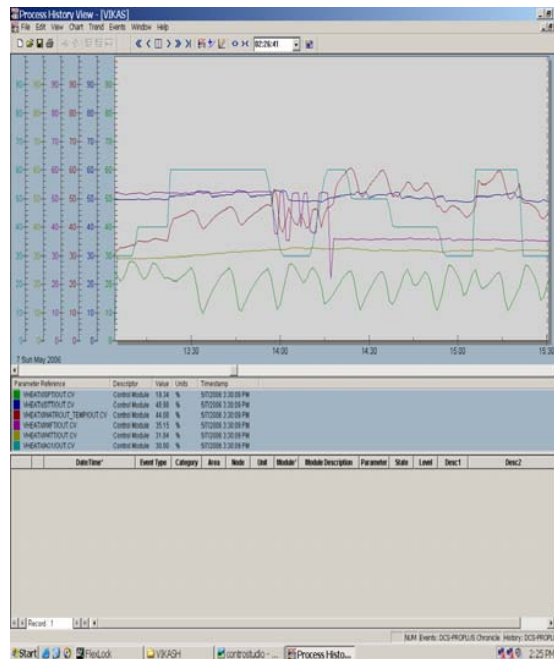Fig. 4 Response of the system to manually generated signal

Fig. 5 System operation at various operating points

To identify the operating region, the process is excited at various operating points, and the region in which the disturbances are minimum, have been considered as operating region of the plant. The response of the system for various step changes is as shown in Fig. 5. By varying inlet water flow also some experiments were conducted. The result of the experimentation is reported in Fig. 5.

In view of the experiments carried out previously it was thought appropriate to experiment further using a technique which useful for nonlinear processes. The technique which has the capability of nonlinear function approximation - rugged, fast and reliable - is neural network for process control. Further experimentation was done for collecting the data for training neural network.

Experiment No. 4: Test the existing tools for the process identification.

Various existing tools are tested for the process identification and control. The data collected is used as basis for generating a process model. Fig. 6 shows the result of PEM Model which has the best performance as regards to other models like GEL, SS etc.

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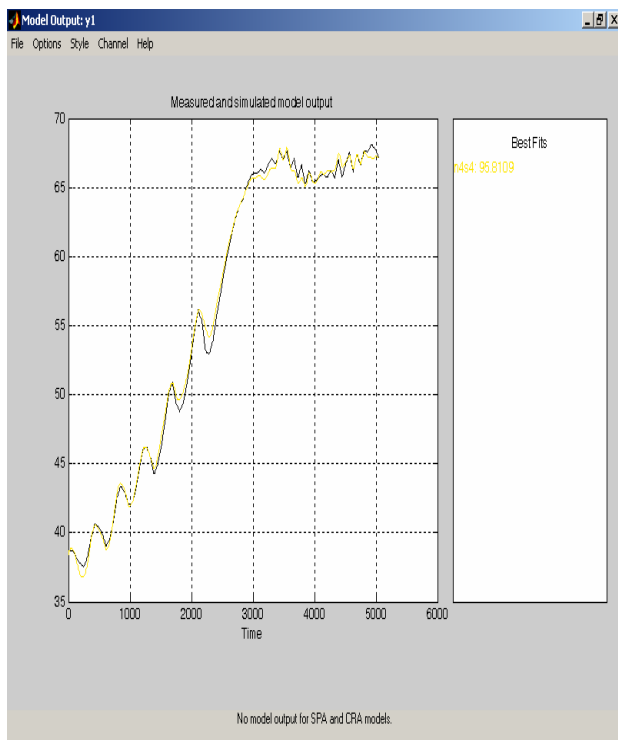
Experiment No. 5: Generate data in tune with control components behaviour and performance degradation.

The experiment carried out for generating data includes excitation within the safe operating limit of the process. Various experiments were performed to collect the data as regards to critical process parameters like steam pressure, steam temperature, water inlet flow, water inlet and outlet temperature. In this case water outlet temperature in %, is the desired variable and % opening of the valve is the input variable. All other variables are treated as disturbances and they are modeled while training the neural networks. At the first instant the water flow and inlet water temperature is kept constant and the valve is opened in the region of interest. The data is collected; the excitation of the signal is varied randomly. The trends so captured are converted using PI facility in the excel sheet. Various neural network topologies are used alongwith variation in no. of processing elements, no. of hidden layers, training rule, and transfer function. The results these experiments are compared on the basis of minimum Mean Squared Error, minimum absolute error, maximum absolute error, and linear cross correlation factor (r). The graph of actual Vs. predicted process is plotted. Fig. 7 shows the best neural network observed so far for the heat exchanger process.
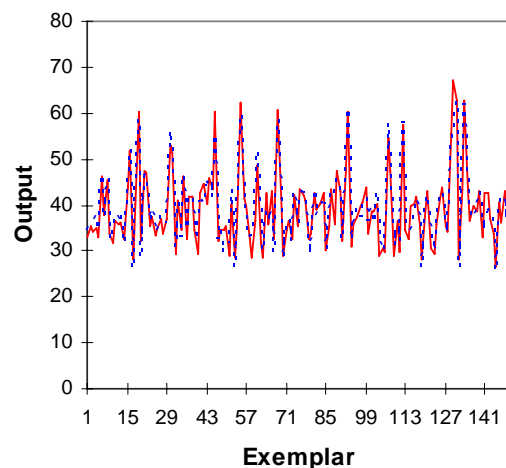

Fig. 7 Actual and predicted water outlet temperature using NN

The results of NN control for the following topology

MLP-1H-18- LM-TANH

The Table I shows the results of the network trained using data generated randomly.

Fig. 6 Actual and simulated water outlet temperature using PEM (Prediction Error Method) model

TABLE I
RESULTS OF NEURAL NETWORK FOR RANDOM DATA

MSE	NMSE	Min. Abs. Error	Max. Abs. Error	(r)
6.0507	0.0871	0.0377	12.4183	0.9556

The performance of the system is not as per the expectation; hence a new PRBS signal was generated. This new signal covers the entire region of operation and dynamics of the process. New sets of readings were taken and similar exercise was carried out to train the neural network. The results are as shown in Fig. 8.
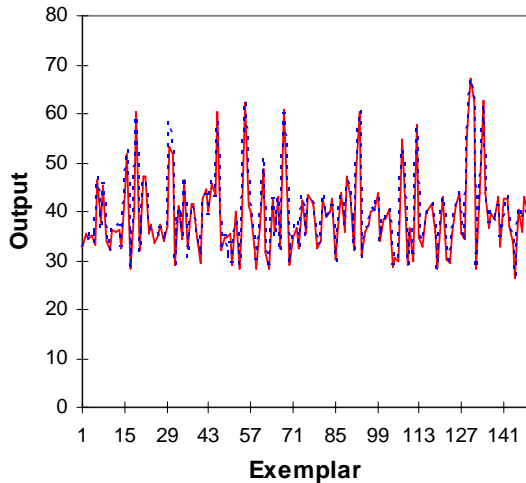

Fig. 8 Actual and predicted water outlet temperature using NN

The results are tabulated in Table II. The results clearly indicate that the performance has improved for the same network topology, hidden layers, no. of processing elements. The results of NN control for the following topology:

MLP-1H-18- LM-TANH

TABLE II
RESULTS OF NEURAL NETWORK FOR PRBS EXCITED DATA

MSE	NMSE	Min. Abs. Error	Max. Abs. Error	(r)
1.3420	0.0201	0.00401	5.2283	0.9899

IV. CONCLUSION

The experiments carried out and the results reveal the fact that if the data generated encompasses the entire spectrum of the process dynamics, then the neural network control is highly successful. It is also observed that for each process a unique PRBS signal needs to be generated. The control components like transmitter, converter, and control valve play an important role in process identification and control. For nonlinear processes, where function approximation is difficult, neural network does the job accurately.

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