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SCG Algorithm for Sensor Fault and Process Fault Detection and Control in Shell and Tube Heat Exchanger

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Abstract
Fault Detection is important in many industries to ensure safe and efficient operation of a process. Actuator faults, sensor faults and process faults are some of the common faults occurring in chemical processes. To identify and control these types of faults in the system Fault detection techniques are proposed. In this present work Sensor and Process faults of shell and tube heat exchanger is detected and controlled using Artificial Neural Network (ANN) via Scaled Conjugate Gradient algorithm (SCG).A set of residuals need to be determined in order achieve fault detection.Residual indicates the state of the system and provide information about the source of possible faults. A fault detection scheme using ANN approach is proposed which are used to generate residuals. The ANN structure chosen for the work is NARX network (Nonlinear Autoregressive with External input). Network is trained using Scaled Conjugate Gradient algorithm. Mean Square Error, Integral Absolute Error (IAE), Integral Time Absolute Error (ITAE) and Integral Square Error (ISE) is obtained which are shown in simulation results. Simulation results also show the response of the process using ANN with and without Proportional Integral Derivative (PID) controller.

Key words: Fault Detection, NARX, ANN, PID, Scaled Conjugate Gradient.

I. INTRODUCTION

Heat exchangers are widely used in practice in many process industries and there are many diverse types of equipment engaged for transferring heat.[2]Shell and Tube Heat Exchangers are one of the most accepted types of exchanger due to the advantage that it can be used for a wide range of pressures and temperatures.[1,3]In general fault in relation to equipment is defined as a deviation from an tolerable range of an experimental variable or calculated parameter associated with the equipment, or a physical defect in the equipment such as a like Failure, on the other hand, corresponds to inoperability of equipment or the process. Actuator fault, sensor fault and process fault are the common faults occurring in chemical process. The fault that occur as a result of a breakage, cut or burned wiring, shortcuts, or the presence of outer body in the actuator are the Actuator faults. Sensor faults represent incorrect reading from the sensors. They can be due to broken wires, loose contact with the surface, etc. Commonly found process faults in heat exchanger includes Fouling, fault in volumetric flow rate etc. In this present work an attempt is made to detect and control sensor faults via ANN. To identify and remove these types of faults in the system, Fault Detection and Diagnosis (FDD) techniques are proposed [3]. These techniques are generally classified as model-based approaches and data-driven approaches some of the model-based FDD techniques include observer-based approach, parity-space approach, and kalman based approach. Data driven approaches include Fuzzy logic, Artificial Neural Network (ANN) and Genetic Algorithm (GA). Faults in complex systems cannot be prevented, the consequences of the faults could be avoided, or at least their severity could be minimized FDD techniques provide early warning to the system operators and prevents the system causing failures. Data driven methods use Soft computing techniques like Fuzzy, ANN and GA as it does not require model and it produce accurate results than model based methods. [4]ANN is used in various application areas such as fault detection and diagnosis, Pattern recognition, system identification, dynamic control purposes. ANN can be used to solve non- linear complex problem since it does not require any information about input or output relationship.

II. RESIDUAL GENERATION

Hardware or physical redundancy methods use multiple sensors and actuators to measure and control a particular variable [14]. The major problems come upon with hardware redundancy is the extra equipment, maintenance cost and additional space is required to hold the equipment. These drawbacks of physical redundancy is overcome by analytical redundancy which is based on residuals [1][14].To achieve FDI, a set of residuals need to be generated. [15]The residual is defined as difference between the measured and estimated process output. To detect and diagnose the fault, FDD has to undergo twostep process namely Residual generation and Residual evaluation [7] as in fig 1. The Residual generator generates a residual and the Residual evaluator compares the residual to determine the occurrence of fault with a threshold [19]. In the ideal case, the residual will be equal to zero when no fault is present and different from zero when a fault is present. A well designed residual signal is defined such that it is equal to zero for fault free case and not equal to zero for faulty system [9].

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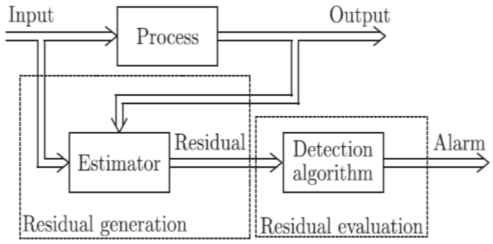

Fig.1. Block Diagram of Fault detection and Diagnosis

III. FAULT DETECTION AND DIAGNOSIS

Fault detection and diagnosis is an important challenge in process Engineering. Actuator fault, sensor fault and process fault are the common faults occurring in chemical process shown in Fig 2. To categorize and eliminate these types of faults in the system, various FDD techniques are proposed .Fault present in any system leads to malfunction of the equipment, fake alarm. In order to determine the kind, size, location and time of fault, many Fault detection and Diagnosis (FDD) Techniques are proposed.The main aim of any FDD method is to raise an alarm if there is any change in the process and to determine the size, location and time of the occurrence of fault [11].

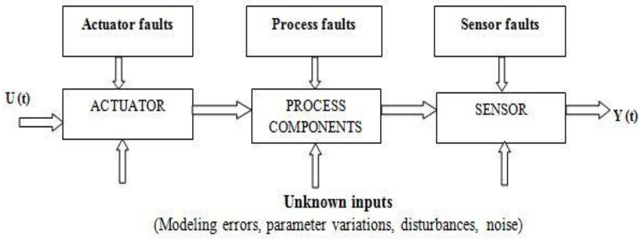

Fig.2. Faults occurring in Heat exchanger

FDD undergoes two step processes namely, Fault detection and Fault isolation. Fault detection is to determine whether the fault has occurred or not. The role of fault isolation is to locate and isolate the fault [12].In this work fault is detected and diagnosed by ANN. [13] Artificial neural networks (ANNs) have the capability to learn the complex relationships between the inputs and the outputs of the system. The ANN understands these relationships on the basis of actual inputs and outputs. ANN provides more accurate results as compared to the other methods which are based on assumptions. One of the great advantages of using a neural network in FDD is its ability to attain input-output mapping. Using input-output mapping a neural network is able to modify its weights by training samples. The training samples consist of an input signal and a desired response. During training the weights are modified in order to reduce the error between the desired response and actual response of the network [17]. Fig 3 shows a general block diagram of ANN based Fault diagnosis.

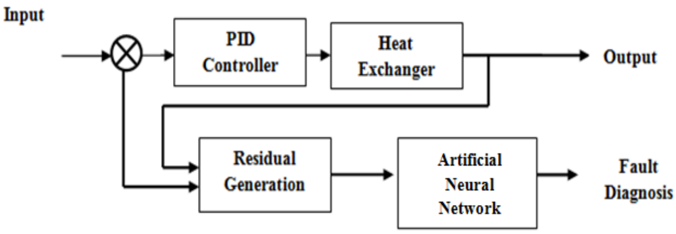

Fig. 3.ANN Based Fault Diagnosis

IV. NEURAL NETWORK CONFIGURATION

In general, [13,15]a neural network is a set of nodes and a set of links. The nodes match to neurons and the links correspond to the connections and the data flow between neurons. Connections are measured by weights, which are tuned during training. [17,18]During training, a set of training instances is given. Each training instance is described by a input vector .It should be linked with a desired output, which is set as another vector, called the desired output vector.ANN consists of number of interconnected units. The input characteristics and its interconnection with other units determines the output of ANN. ANN generally consists of Input layer , Output layer and hidden layer with a number of nodes in it. Input layer does not have input weights and activation function. The output response for a given input is determined by the output layer. Hidden layer has no connection with outside world. Increasing the number of hidden layer increases the complexityof the network but it results in accurate results. Generally ANN structure has to be trained prior to fault detection and diagnosis. Back propagation, Nonlinear Autoregressive (NAR),[17,18]Nonlinear

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Autoregressive with External Input(NARX), multilayer feed forward network, Multi-layer perceptron network are some of the training methods of ANN. Among these training methods of ANN, Nonlinear Autoregressive with External Input(NARX) provide better results since it predicts past values of input and output.Neural networks are mostly classified as static networks and dynamic networks. The output of the static network depends only on the current input of the network and it has no delay elements and feedback elements. Dynamic network are more advantageous than the static networks because the output of the dynamic network depends on the current input as well as on previous inputs and outputs. NARX structure belong to dynamic network which have feedback or recurrent connections with delay input. Here NARX is used as network structure which shows more accurate results since it calculate the past values of y(t) and x(t).These neural networks have the ability to predict the future values based on the values at the previous instants. Implementation of NARX model is shown in Fig 4.

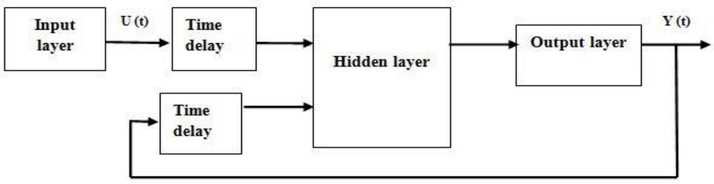

Fig. 4. Implementation of NARX model

V. SCALED CONJUGATE GRADIENT (SCG) ALGORITHM

Scaled Conjugate Gradient algorithm is a supervised learning algorithm. SCG is a batch learning method and there will be no effect if parameters are shuffled. [14,15] Many of the training algorithms are based on the gradient descent algorithm. Minimization is a local iterative process in which an approximation to the function, in a neighbourhood of the current point in the weight space, is minimized. SCG is related to the group of Conjugate Gradient Methods, which illustrate super linear convergence on most problems. SCG avoids a time consuming line-search per learning iteration, which makes the algorithm more rapidly via step size scaling mechanism. [17]trainscgis the training function for scaled conjugate gradient method [16] .This algorithm takes only a little memory. Training automatically ends when generalization endsimproving when there is increase in the mean square error of the validation samples. General block diagram of ANN based fault diagnosis of heat exchanger using scaled conjugate gradient method for sensor faults with PID controller is shown in Fig 3.simulation results are shown in Fig 5 to Fig 7.

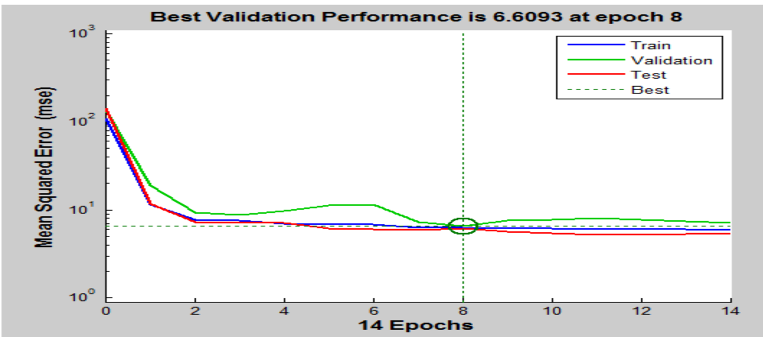

Fig.5. Mean square error graph for Sensor faults

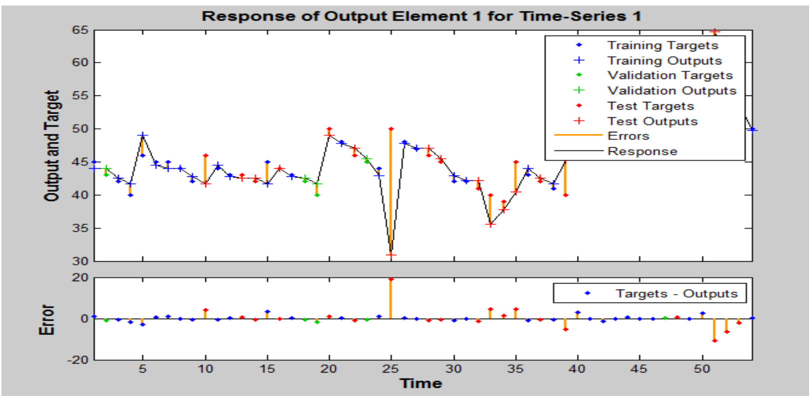

Fig. 6. Error graph for Sensor faults

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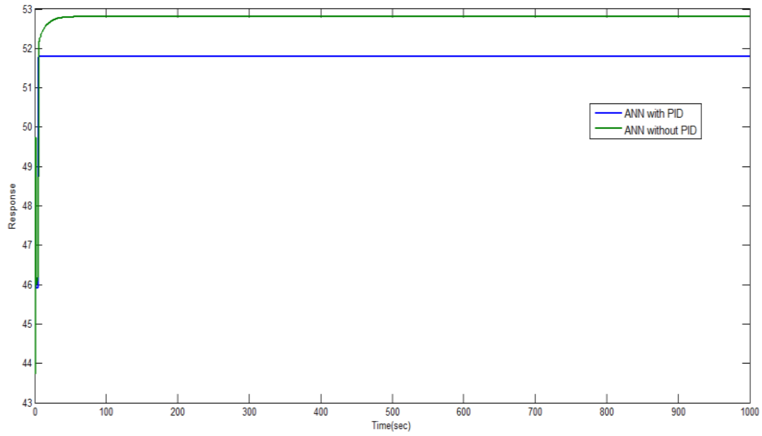

Fig.7. Response of ANN with and without PID for Sensor faults

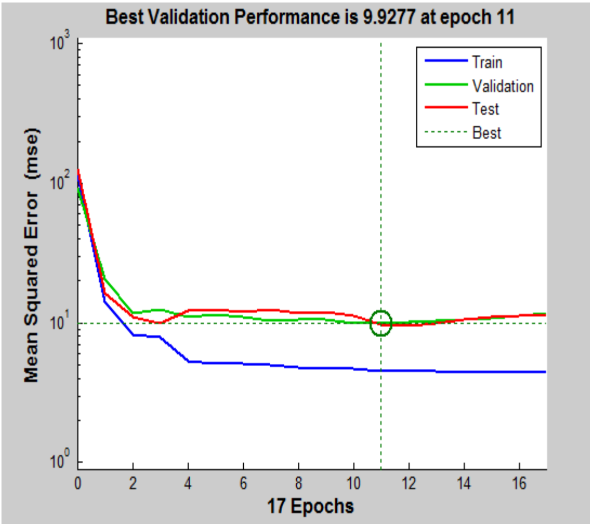

Fig. 8. Mean square error graph for process faults

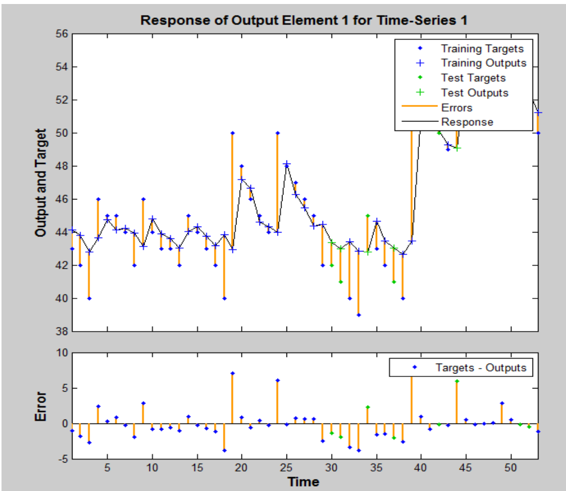

Fig. 9. Error graph for Process faults

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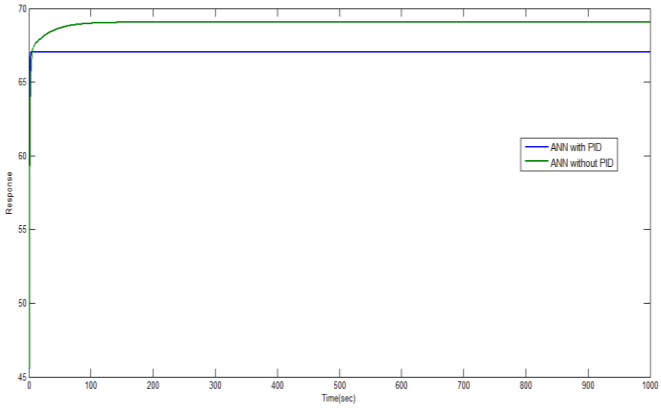

Fig. 10. Response of ANN with and without PID for Sensor faults

VI. RESULTS AND DISCUSSION

In this work a supervised learning algorithm (Scaled Conjugate Gradient) is proposed.[17] SCG belongs to the group of Conjugate Gradient Methods, which show super linear convergence on most problems. SCG avoids a time consuming line-search per learning iteration via aa step size scaling mechanism, which makes the algorithm more rapidly. This algorithm takes only a little memory. Training automatically ends when generalization ends improving when there is increase in the mean square error of the validation samples. Various parameters of Scaled conjugate gradient for sensor faults are compared which are shown in table 1.Integral Absolute Error (IAE), Integral Square Error (ISE) and Integral of Time and Absolute Error (ITAE) is calculated for sensor and process faults with and without PID controller and the comparative results are shown in table 2 and table 3.

Table1. Comparative results of training algorithm for sensor Faults

Parameter	**Scaled conjugate gradient**	
	Sensor Fault	**Process Fault**
Number of hidden neuron	40	50
Delay	1	1
Training Function	Trinscg	Trinscg
Training Mean Square Error	6.6093	4.49742
Validation Mean square Error	13.9901	9.92767
Testing Mean Square Error	31.1090	9.72641
Epoch	8	11

Table 2. Error calculation for sensor fault with and without PID

Sensor fault with PID			**Sensor fault Without PID**		
ITAE	**IAE**	**ISE**	**ITAE**	**IAE**	**ISE**
5026	2513	1.265×10^5	5098	2549	1.30×10^5

Table 3. Error calculation for Process fault with and without PID

Process fault with PID	**Process fault Without PID**

ITAE	IAE	ISE	ITAE	IAE	ISE
1.315×10^5	6.676	4.33×10^6	1.342×10^4	6711	4622

VII. CONCLUSION

A supervised learning algorithm (Scaled Conjugate Gradient)is introduced. SCG belongs to the class of Conjugate Gradient Methods, which show super linear convergence on most problems. Sensor fault for shell and tube heat exchanger was detected and controlled using ANN. Training of ANN is done by Scaled conjugate gradient method. Various parameters of network such as Mean Square Error, Number of hidden layer, Epoch,Integral Absolute Error (IAE), Integral Square Error (ISE) and Integral of Time and Absolute Error (ITAE) are obtained. Response of the process using ANN with and without PID controller is obtained.

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