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Neural Network Based PI Controller Parameter Calculation on a Boiler Drum Level System

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Abstract

The controller parameters influence the performance of the closed loop system. So we have to develop a tuning method for obtaining the optimum values of the controller parameters with respect to a particular process. Controller tuning is very much process dependent and any improper selection of the controller settings may lead to instability and affect performance of the closed loop system. Closed loop tuning methods like Ziegler-Nichols method depends on estimation of ultimate gain and ultimate time period. When trying different gains on an unknown process the amplitude of undampened oscillations can become unsafe or on the conversely for low initial gain settings the test can take a long time to reach sustained oscillation condition. This paper proposes a neural network based scheme to estimate ultimate gain and optimum proportional and integral value of PI controller within affordable time limit and safe input range when the parameters change.

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Keywords: Back propagation algorithm; Levenberg-Marquadrt algorithm; Neural network; PI controller

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Introduction

Many processes are automatically controlled in different industries. Two control methods, which are widely used in many industrial control applications**,** are PI- and PID controllers. The majority of industrial control loops is still rely on the PID controller [11]. The derivative term is not widely **used;** hence over 90% of the industrial controllers are of the PI type [11]. Here PI controller is applied to boiler drum level control system. Drum level control is widely used throughout the process industry [12]. In boiler drum, decrease in water level may cause them to become overheated and get damaged. An increase in water level may affect the process of separating moisture from steam within the drum and cause loss of efficiency [10, 12]. Conventional PI controller still dominates the process industries, due to its functional simplicity, robustness and effectiveness over a wide range of operating conditions. The main task in designing a PI controller is to determine the proportional gain (k_p) and integral gain (k_i) of the controller. These parameters of PI controller should be tuned appropriately. There are various methods available for tuning proportional and integral gains of PI controllers. One of the methods widely seen in literature is Ziegler-Nichol tuning. Ziegler- Nichols method depends on estimation of ultimate gain and ultimate time period. This involves trying various values of gain on a real time system. When trying different gains on an unknown process the amplitude of undampened oscillations can become unsafe or on the contrary (for low initial gain settings) the test can take a long time to reach sustained oscillation condition [1]. Thus, we have to develop a tuning method for finding the ultimate gain and ultimate period within reasonable time without unsafe oscillations.

Neural networks have strong self-learning and self-adapting capability [11]. They can adapt to new scenarios, and fault tolerant. In this Paper we design a neural network to find the ultimate gain from the step response of a system for duration of 35 seconds. This paper also designs a neural for obtaining optimum proportional and integral values from ultimate gain and step response for duration of 35seconds. It is needless to say that the controller parameters influence highly on the performance of the closed loop system. And the parameters of the various industrial processes are liable to change due to aging, thus an NN based scheme as proposed in this project can be a useful tool for updating optimal PI setting from time to time to compensate for change in system parameters accrued over time.

2. Process Model

One of the important control loop on a steam boiler is the steam drum level controller. It consists of a steam drum, whose level is measured and transmitted to a level controller by a level transmitter. The control signal from the level controller actuates a valve controlling feed water flow. Feed water flow is measured by flow transmitter. The level-controller adjusts the feed water flow according to the level changes in the drum [2].

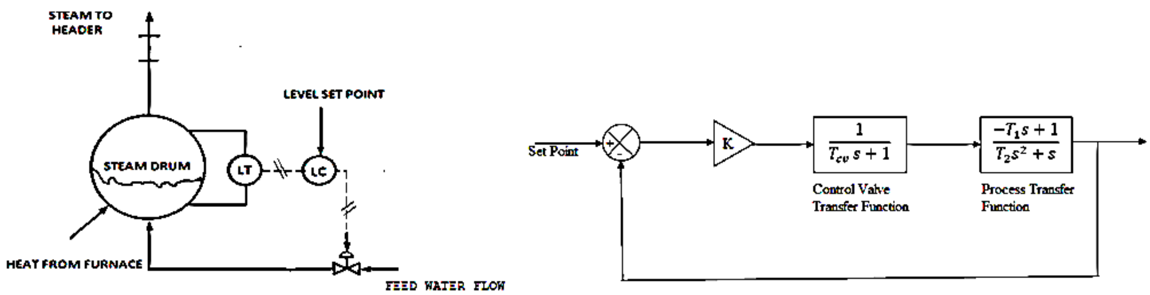

Fig. 1 (a) Control Instrumentation diagram for steam drum level control; (b) Block Diagram of Boiler drum level control system

Fig 1(b) shows the general block diagram of the boiler drum level control system. This Block diagram includes transfer function for analysis of boiler drum level and control valve transfer function [21].The relationship between the feed water flow rate and drum level is given by [2]

$$G_p(s) = \frac{-T_1 s+1}{T_2 s^2+s} \quad (1)$$

Assume that valve transfer function is

$$G_v(s) = \frac{1}{T_{cv}\, s+1} \quad (2)$$

Input of the control valve is controller output and output is the flow rate. K is the gain, T_{cv} is the control valve time constant and T_1, T_2 are process parameters. Changing of these parameters will affect the performance of the boiler. So here we design a neural network to find the PI gains of the system when the parameter T_1, T_2 change.

3. Controller Tuning

A PI controller is commonly used in process control systems. A PI controller has two parameters, Proportional gain and Integral gain, which are denoted by P and I. P depends on present error and I depends on the accumulation of past errors. Tuning these two parameters suitably can provide desired controller action designed for specific process requirement. Different tuning methods are available. The comparison of various tuning method are shown in table 1 In this paper a neural network based tuning methodology is developed to overcome the drawbacks of these tuning methods.

Table 1. Comparison of different tuning Method

Method	Advantage	Disadvantage
Manual tuning	No mathematical calculation needed, online method	Required experienced Personnel, time consuming,
Cohen-Coon	Good process model	Some mathematical calculation is required, good for only first order process [6]
Ziegler-Nichol	Easy method, used for any order of system	Process upset, some trial and error, time consuming [6]

3.1. Neural Network

Neural networks are a new artificial intelligence technique. It is a Powerful tool that has the ability to identify complex relationship from input-output data [10]. ANNs has the ability to adapt their behavior to the changing characteristics of the system [7]. The learning procedure is tries to find values for a set of connections w that gives a mapping between inputs and outputs to fit well with the training set.

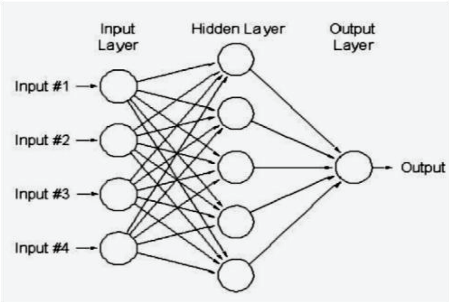

Fig. 2. Structure of Neural Network

The main advantage of ANN is the capability to model a problem by the use of data associated with process. In this model the system output error is back propagated through plant using its partial derivatives from a set of actual system. Output are selected as a training data and provided as input to ANN during its training period. By comparing the output of ANN with desired system output, the new output error is computed which is then used to train the NN. After NN is well trained, it can be used to give satisfactory output for a given set of inputs [10].
The objective of training an NN is to produce desired output when a set of input is applied to the network; the training of NN is based on the back propagation algorithm. The mathematical algorithm which is used for training of a network will also affect how successful the trained network is. Back Propagation Neural Network (BPNN) algorithm is used for training multilayer feed forward neural network algorithm [13]. It is effective, and easy to learn for complex, multilayered networks.

3.2.Back Propagation Algorithm

Back propagation algorithm is one of the most popular neural network algorithms [13]. Back propagation is a method for training multilayer neural networks which uses the procedure of supervised learning. Supervised algorithms are error-based learning algorithms which utilize an external reference signal and generate an error signal by comparing the reference with the obtained output [18]. The Back propagation algorithm learns by calculating the errors of the output layer to find the errors in the hidden layers. Due to this property, Back-Propagating algorithm, is highly suitable for problems in which there is no relationship is found between the input and output [3]. Due to its flexibility and learning abilities, ANN has been successfully implemented in wide range of applications.

3.3.*Levenberg-Marquardt Back Propagation Algorithm*

The Levenberg-Marquardt algorithm is a very simple, but robust, method for approximating a function. The Levenberg-Marquardt algorithm basically involves solving equation (3) with different $'\mu'$ values until the sum of squared error decreases [5].

$$X_{k+1}=X_k-[J^TJ+\mu I]^{-1}J^Te \quad (3)$$

J - Jacobian matrix that contains first derivatives of the network errors with respect to the weights and biases. In the neural network case, it is an N-by-W matrix, where N is the number of entries in our training set and W is the total number of parameters (weights + biases) of our network .

4. Neural network training

In this work, a large number of transfer functions have been created by random. Then, the step responses, ultimate gain and PI-parameters for these transfer functions have been calculated. As input data for the neural network, different points at the step responses have been chosen and as output data the PID-parameters are chosen. The purpose of the networks is to calculate PI-parameters for different processes; first we design a neural network for finding the ultimate gain of the system and then design NN for PI parameter. Training is done using neural network fitting tool (nf tool).

4.1. Neural Network for Ultimate Gain Prediction

Training data for the NN was obtained by taking samples of step response of different process transfer functions as input set and ultimate gains for each transfer function as target set. Here input set is obtained from 71 samples from step response to each transfer placed in place of process transfer function in Fig 3, with K=1. The target for a transfer function is the value of K for which the loop exhibits sustained oscillations.

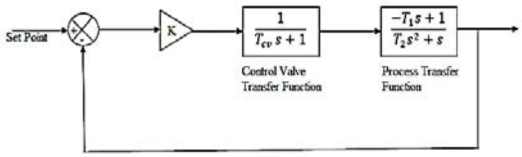

Fig. 3.Block Diagram used for neural network training

Training set was obtained by forming different process transfer functions by changing T_1 by 0.05 keeping T_2 constant for 20 cases and changing T_2 by 1 keeping T_1constant, for another 20 cases. Input set was taken from samples of step response for each transfer function taken at an interval of 0.5 s for duration of 35seconds.

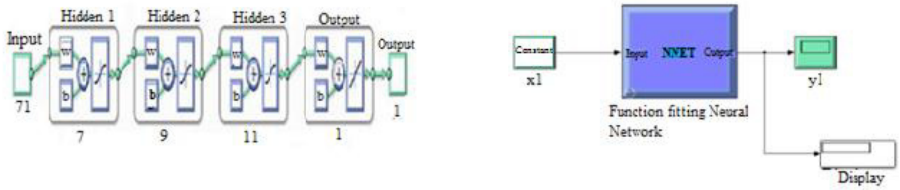

Fig 4 (a) Neural Network Architecture for ultimate gain; (b) Simulink diagram of Neural Network for ultimate gain

The Fig. 4 (a) shows the neural network architecture found optimal for ultimate gain prediction. Consist of an input layer, 3 hidden layer and one output layer and size of the hidden layer chosen as [7 9 11]. Fig 4 (b) shows Simulink diagram of arrangement for obtaining ultimate gain. Here the input to neural network is the 71 samples obtained over 35 seconds from the step response of the system whose ultimate gain is to be predicted. The designed neural network displays the ultimate gain of system corresponding to given input.

4.2.Neural Network for Finding PI Gains

The Neural network was designed by forming a training set with target set consisting of different optimum P and I values for different transfer functions in the system shown in Fig 5, and input set consisting of its ultimate gain and samples from step response, when controller gain is unity.

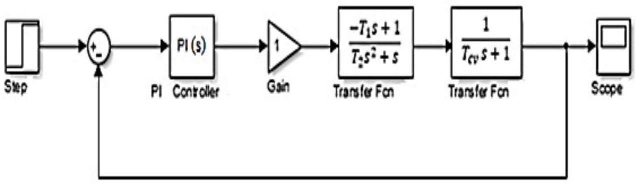

Fig. 5. Block diagram of PI controller applied to plant

The optimum P and I gains were calculated for obtaining rise time less than 15sec and overshoot less than 20sec. P and I values were calculated for, a set of 7 different process models formed by varying T_1 by 0.05 keeping T_2 constant and a set of 8 different process models formed by changing T_2 by 1 keeping T_1constant. Input set was obtained by samples from step response of each model at sampling time of 0.5 s for a duration of 35sec.

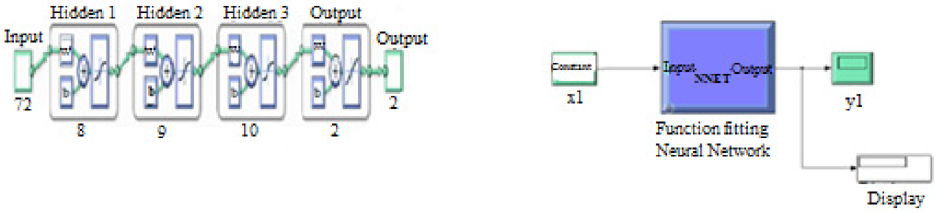

Fig. 6 (a) Neural network Architecture used to obtain PI values ; (b) Simulink Diagram of neural network

Training is done using neural network fitting tool (nf tool). The structure of NN is shown in Fig 6(a) and its implementation in SIMULINK is as shown in Fig 6(b). The designed NN has 72 inputs consisting of ultimate gain as one input and 71 samples of step response for the remaining 71 inputs. The network gives optimum P and I values as its output.

5. Conclusion

The paper presents a method to use capability of neural networks to solve process control problem of finding optimum P and I parameters of a PI controller, within finite time without dangerous oscillations. The capability of designed NNs to predict ultimate gain and P & I parameters matching requirement specific to a given training set was verified using simulations discussed in this paper.

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