Application of Artificial Neural Network for Improved Relay Tuning of Controller

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Abstract— The first order plus time delay (FOPTD) model was assumed and the improved relay tuning method was applied for tuning with higher order of relay harmonics. A relay feedback test was conducted to obtain a symmetric relay response and ultimate gain. Then Ziegler-Nichols optimum controller parameter method was applied for estimation of optimum control parameters for the given system. The Artificial Neural Network was applied to the closed loop model. It was found that the predicted model response was close to that of actual one.

Index Terms— Relay Tuning, ANN.

I. INTRODUCTION

Control plays a key role in the operation of chemical plants with respect to economical performance, safety and operability. In a typical chemical plant there are hundreds of PID feedback loops. They are often poorly tuned because the choice of PID controller parameters requires professional knowledge by the user. One of the most common approaches to tune a controller automatically is to connect a relay as a feedback controller to the process during tuning.

Astrom and Hagglund [1] have suggested the use of an ideal (on-off) relay to generate a sustained oscillation of the controlled variable and to get the ultimate gain (k_u) and the ultimate frequency (ω_u) directly from the relay experiment. The relay feedback method has become very popular because, it is time efficient as compared to the conventional method. The amplitude (a) and the period of oscillation (p_u) are noted from the sustained oscillation of the system output. The ultimate gain (k_u) and ultimate frequency (ω_u), are calculated from the principal harmonics approximation as given by equation;

$$K_u = \frac{4h}{\pi a} \quad (1)$$

$$\omega_u = \frac{2\pi}{P_u} \quad (2)$$

Luyben [3] has suggested the use of relay testing for identifying a transfer function model. Using k_u and ω_u in the phase angle and amplitude criteria for an unstable FOPTD model, the following two equations relating three model parameters are obtained

$$\frac{K_u K_p}{(1 + \tau^2 \omega_u^2)^{0.5}} = 1 \quad (3)$$

$$D\omega_u - \tan^{-1}(\tau\omega_u) = 0 \quad (4)$$

Since only k_u and ω_u are available, additional information such as the steady state gain, or the time delay should be a known priori in order to fit a typical transfer function model such as unstable FOPTD. The above Equations assume that, the higher order harmonics are neglected. **Majhi and Atherton [4, 5]** have proposed an improved method for calculating the FOPTD model parameters by a symmetric relay tuning. In this method, the output response is aligned with the input response by shifting to the left. The area under the curve for the process output response over a half period of the cycle is calculated (a_y). The corresponding net area for the process input response over the half period of the output response is also calculated (a_u). The steady state gain k_p is estimated as;

$$K_p = \frac{a_y}{a_u} \quad (5)$$

$$\tau = \frac{\frac{P_u}{2}}{\ln\left(\frac{k_p h + a}{k_p h - a}\right)} \quad (6)$$

$$D = \frac{\frac{P_u}{2} \ln\left(\frac{k_p h + a}{K_p h}\right)}{\ln\left(\frac{k_p h + a}{k_p h - a}\right)} \quad (7)$$

Recently **Thyagarajan and Yu [9]** have proposed a method of identifying a FOPTD unstable model based on the shape of the response of the process using a symmetric relay. In this method, the output response is aligned with the input response by shifting to the left. Then, the time to peak amplitude, the peak amplitude and the period of oscillation are noted. The time delay is considered as the time to the peak value. From the derived analytical expression of the process output response of an unstable FOPTD system for a symmetric relay input, the time constant and gain are calculated as

$$\tau = \frac{\frac{P_u}{2}}{\ln\left(\frac{1}{2e^{D/\tau} - 1}\right)} \quad (8)$$

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$$K_p = \frac{a}{h(e^{D/\tau} - 1)} \quad (9)$$

It is to be noted that, for higher order systems, the recorded time to peak value from the response (D) will not match with that of the actual time delay of the process. **Li, Eskinat, and Luyben [2]** have reported that the model identified by the symmetry relay auto tune method gives error as high as 27 to -18% in the value of ku for stable FOPTD systems. Recently, **Srinivasan and Chidambaram [8]** proposed a method of considering higher order harmonics, to explain the reported error of 27 to -18% in ku calculations for stable systems. **Sathe Vivek, M. Chidambaram [7]** proposed a method by incorporating the higher order harmonics to explain the error in the ku calculation. The relay equation is given as;

$$y(t^*) = a[1 + (1/9) + (1/25) + (1/49) + (1/81) + \dots]. \quad (10)$$

II. ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons. Artificial neural networks have been used in recent years to avoid the problems associated with deterministic approaches, and have been shown to approximate nonlinear functions up to any desired level of accuracy [6]. They are also less sensitive to noise and incomplete information than other approaches such as empirical models and correlations. The advantage of using ANNs to simulate processes is that, after they are trained, they represent a quick and reliable way of predicting their performance. They can also be continuously updated. Thus, if we apply this technique to the problem of simulation and control of process, then we obtain an accurate prediction with a short computational time for the simulation which can be used in an efficient real-time control scheme. There are several schemes that have been proposed for the neural control of nonlinear systems.

In this work, the combined advantages of ANNs and improved relay tuning have been used to generate an efficient control scheme for a given process.

The results of the neural control are compared with those of standard PID techniques.

III. MATERIALS AND METHOD

A process having the following FOPTD transfer function model was considered;

$$G_p = \frac{e^{-0.2}}{s-1} \quad (11)$$

Then the Simulink diagram for relay tuning was prepared as shown in fig 1. The relay experiments were carried out for relay height as 0.2 and N as 5. The corrected amplitude (a) [8], period of oscillations (P_u) was noted and ultimate gain was calculated.

The PID controller tuning parameters were calculated using Ziegler-Nichols [10] optimum controller parameter method as shown in Table 1. The Artificial Neural Network was applied to the closed loop model. The predicted model response was compared to that of the actual one.

TABLE I. ZIEGLER-NICHOLS OPTIMUM CONTROLLER PARAMETER

Controller	K_c	τ_i	τ_D
PID	$0.6K_u$	$P_u/2$	$P_u/8$

Fig 1: Simulink Diagram for Relay Control

Fig 2: Relay Response

Fig 3: Process Response

Fig 4: Simulink Diagram for PID Control

Fig 5: Training with Trainlm

Fig 6: Testing Data for NN Predictive Control

Fig 7: Validation Data for NN Predictive Control

Fig 8: Training Data for NN Predictive Control

IV. RESULT & DISCUSSION

For improved relay tuning, two parameters i.e. relay height (h) as 0.2 and number of harmonics in relay equation (N) as 5 were considered. The experiments were conducted and ultimate gain (Ku) was estimated. The Simulink diagram, relay response and process response are shown in figure 1-3 respectively.

The PID controller tuning parameters were calculated

using Ziegler-Nichols [10] optimum controller parameter method as shown in Table 1. The estimated PID parameters found to be $K_c=4.2$; $\tau_i = 0.4$ and $\tau_D=0.1$.

The ANN was applied to the closed model and the Training with Trainlm, Testing data for NN Predictive control, validation data for NN Predictive control and Training data for NN Predictive Controls are presented in fig 5 to fig 8 respectively.

V. CONCLUSION

In this study, an improved Relay-tuning scheme [7] for FOPTD process is used and an Artificial Neural Network (ANN) is applied. By using this scheme, the Relay parameters are optimally and robustly adjusted with respect to the system dynamics. This method can be easily extended to multi-input and multi-output systems from basic single-input and single-output systems. The ANN is applied to the closed loop model for prediction of performance. The simple structure, robustness and ease of computation of the ANN method make it very attractive for real time implementation for control of given process. The prediction given by ANN method is closed to that of the actual performance.

NOMENCLATURE;

- Pu -Period of oscillation
- Ku -Ultimate gain
- ω_u -Frequency of oscillation
- h -Relay height
- a -amplitude
- N -No. of harmonics in relay equation
- kc -Controller gain
- τ_i -Integral time, sec
- τ_D -Derivative time, sec

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