Modified Smith Predictors for Control of FOPLDT Processes

Aruna B¹, Neethu Mary², Jimisha K³, Angel Augustine⁴
¹,²,³,⁴ Department of Control and Instrumentation, Vimal Jyothi Engineering College, Kannur, India

Abstract: The long time delay in control systems is one of the main difficulties in controlling industrial processes. The time delay causes poor stability and large over shoots. The Smith predictor and its modifications are simple and commonly used controllers to deal with time delayed systems. This paper discusses about the two modifications of standard Smith predictor. A fuzzy self adaptive PID Smith predictor and a Neuro-fuzzy compensator based Smith predictor. In the fuzzy self adaptive PID Smith predictor, a fuzzy PID controller is used which utilizes the principle of fuzzy control to tune the parameters of PID controller online. On the other hand a Neuro-fuzzy compensator based Smith predictor utilizes both fuzzy logic and a back propagation neural network to compensate for time delay problems.

Keywords: Process control, Smith predictor, Neuro-fuzzy compensator, Self adaptive, Long time delay, Fuzzy PI control.

I. INTRODUCTION

Long time delays in industrial processes makes it difficult to use conventional P, PI & PID controllers to achieve good performance. Smith predictor and its modifications are used commonly to compensate for time delays[1]. But, the problem with Smith predictor is that it relies highly on the accuracy of the predicting model and therefore sensitive to modeling errors.

In order to reduce the negative impact caused by model mismatch, an improved fuzzy-adaptive PID Smith predictor is used. It combines the fuzzy self tuning PID controller and the gain adaptive regulator. It not only solves the large overshoot of the long time delay system, but also holds better stability & adaptive capacity[2-3].

In second method, a back propagation neural network & a fuzzy logic based compensator are used to compensate for modeling mismatches and compensate for time delays. It achieves better settling time & avoids model mismatch & time delay problems[4].

II. SMITH PREDICTOR

A standard Smith predictor is indicated in Fig. 1.

Fig.1: Smith predictor

The closed loop transfer function is given by,

\[
Y(s) = \frac{C(s)G(s)e^{-Ls}}{R(s) + C(s)G_n(s) - C(s)G_n(s)e^{-Ls} + C(s)G(s)e^{-Ls}}
\]

The transfer function of the process is,

\[
G(s)e^{-Ls} = \frac{k}{\tau s + 1} e^{-Ls}
\]

The transfer function of the model is

\[
G_n(s)e^{-Ln_s} = \frac{k_n}{\tau_n + 1} e^{-Ln_s}
\]

With an accurate model, the closed loop transfer function is given by

\[
Y(s) = \frac{C(s)G(s)}{1 + C(s)G(s)} e^{-Ls}
\]

But in practical cases there will always be some modeling errors and hence we don’t get the accurate response as above. Therefore we use modified Smith predictors as explained below.

III. FUZZY SELF-ADAPTIVE PID-SMITH CONTROL SYSTEM

In view of the long time-delay characteristics of industrial systems and considering the drawbacks of simple Smith predictors, fuzzy self-adaptive PID-Smith control method is proposed. They makes use of Smith predictive control to compensate for time-delay, fuzzy control to overcome change of model parameter, uncertainty, at the same time, adjustable PID controller is tuning on-line by fuzzy logics to improve the control accuracy in steady state. This scheme, which combines the fuzzy self-tuning PID controller and the gain adaptive regulator, not only can solve the large overshoot of the long time delay system, but also holds a better stability and adaptive capacity.
IV. DESIGN OF THE FUZZY ADAPTIVE PID-SMITH PREDICTOR

Once the model mismatch occurs in the actual production process, the system response will be unstable and have substantial oscillation [5]. As a result, it is difficult to obtain satisfied performance for the simple Smith predictor. In order to get a better performance, a fuzzy self-tuning PID Smith prediction controller, which combines fuzzy self-tuning PID controller and the Smith predictor to improve the robustness and stability, is proposed [6]. However, simulation results indicate that this method is just suitable for the model parameters changes within 20%. When it reaches more than 20%, the effect of the fuzzy self-tuning PID controller will be small and the performance will be significantly worse, even divergent. For the limitations of above predictor controllers, a new fuzzy adaptive PID-Smith predictor controller is developed by combining the fuzzy self-tuning PID controller and the gain adaptive regulator, as shown in Fig.2.Where \( R(s) \) is the input of the system, \( Y(s) \) is the output of the system, \( k_m \) is the proportional gain, \( G_m(s) e^{-\tau m s} \), \( G(s) e^{-\tau s} \), \( G_c(s) \) are, respectively, the plant’s dynamic model, and the transfer functions of the plant and the primary controller which uses the self-tuning PID controller instead of the traditional PID controller.

The structure of a fuzzy adaptive PID Smith predictor is shown below.

![Fig.2. The structure of the fuzzy adaptive PID Smith predictor](image)

V. SIMULATION ANALYSIS

Selecting an industrial electric furnace as the controlled object whose transfer function is,$$G(s) = \frac{1}{60s + 1} e^{-40s}$$Applying a 40% change in all parameters of the plant, the transfer function becomes:$$G(s) = \frac{1.4}{84s + 1} e^{-50s}$$Now the system response becomes as shown below.

![Fig.3. System responses](image)

The dotted (blue) line is the response of the conventional Smith control and the dash (green) line is the response of fuzzy self-tuning PID-Smith control and the solid (red) line is the response of proposed method. According to the simulation results of Fig. 2, some important performance indicators are given and they are listed in Table 1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Maximum Overshoot</th>
<th>Maximum Adjustment Time</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>The simple Smith</td>
<td>50.5</td>
<td>1000</td>
<td>Stable</td>
</tr>
<tr>
<td>The fuzzy self-tuning PID Smith</td>
<td>48.9</td>
<td>1000</td>
<td>Stable</td>
</tr>
<tr>
<td>The fuzzy self-adaptive Smith</td>
<td>0.1</td>
<td>875</td>
<td>Stable</td>
</tr>
</tbody>
</table>

It can be seen that both the fuzzy self-tuning PID-Smith control and the conventional Smith control has large overshoot. It indicates that the effect of the fuzzy self-tuning PID controller is small when the model mismatch comes to 40%. Compared with the other methods, the fuzzy self-adaptive Smith predictor only has a little overshoot. What’s more, it has shortened the adjustment time and has small oscillation amplitude, even when the model mismatch rate comes to 40%. As a result, the fuzzy self adaptive method not only can solve the large overshoot of the long time delay system, but also holds a better stability and adaptive capacity.

VI. NEURO-FUZZY-COMPENSATOR-BASED SMITH PREDICTOR

A three-layer structure of back propagation neural network (BPNN) is shown in Fig. below. The number of nodes to the input layer equals to the number of controller inputs. The number of nodes from the output layer is the number of controller outputs. The fuzzy-logic-based compensator is simulated by considering very small simultaneous variations in all three model parameters. [4]. Data were collected from the system inputs and outputs as shown in Fig.
modified Smith Predictors for Control of FOPLDT Processes

In this structure, \( ir \) and \( ip \) are the gathered data from the overall system reference input and output respectively. They are both applied as inputs to the BPNN controller. \( oc \) is the collected data from the controller output. It sets the target output of the BPNN controller. The structure of the BPNN controller is shown in Fig. 6.

This network is trained offline by using the collected data. However, simulation results indicate that this controller does not remove a steady state error due to process gain mismatch. To reduce the steady state error, a PID controller is applied.

VII. SIMULATION ANALYSIS

The model of the dynamic process used to design the Smith predictor is represented by the transfer function

\[
G(s) e^{-6s} = \frac{1.59 + \Delta k}{(28 + \Delta \tau)s + 1} e^{-61s}
\]

For evaluating the proposed approach, the model is considered to have inaccuracies with variations in its gain, time constant and dead time parameters. The process plant is represented with the transfer function

\[
\frac{1.59}{(28s + 1)} e^{-61s}
\]

where \( \Delta k \), \( \Delta \tau \) and \( \Delta L \) are the modeling variations in parameters gain, time constant and dead time respectively.

Now consider simultaneous process modeling errors to evaluate the neuro-fuzzy-compensator-based Smith predictor and the standard Smith predictor for comparison. Assume the process transfer function to be

\[
\frac{1.908}{(22.4s + 1)} e^{-48.8s}
\]

20% variation in process gain and +20% modeling errors in process time constant and dead time. Simulation results are given below to evaluate the proposed control approach.
Modified Smith Predictors for Control of FOPLDT Processes

Aruna B et al

Smith predictor for a process control with the same modeling errors, the response of which is shown in Fig. Further simulations were conducted to provide the tolerated mismatch ranges for stability of both the proposed approach and the standard Smith predictor in the presence of simultaneous process modeling errors.

The neuro fuzzy-compensator-based Smith predictor could deal with first-order-plus-long-dead time process control by taking into account modeling errors in all three process parameters, namely gain, time constant and dead time. It outperforms the standard Smith predictor for the control of an inaccurately modeled process. A large number of simulations demonstrated that this control scheme increases significantly the robustness of the FOPLDT process.

VIII. CONCLUSION

In this paper two modifications of standard Smith predictor are discussed, namely Neuro-fuzzy compensator based Smith predictor and Self adaptive fuzzy tuned Smith predictor. Simulation results indicate that, out of these two methods, the settling time of fuzzy self adaptive Smith predictor is longer than that of the Neuro-fuzzy compensator based Smith predictor. At the same time maximum overshoot is higher for neuro-fuzzy compensator based Smith predictive controller than that of fuzzy self adaptive PID Smith predictor. Anyway, both the controllers outperforms standard Smith predictor, in presence of simultaneous modeling errors, for controlling processes with long time delays.

REFERENCES