Deaerator Tank Level Control using Direct Synthesis Tuning Method

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Abstract: The gases separation from the feedwater in the deaerator is done by heating process. When the temperature inside the deaerator increases, the volume of the feedwater will decrease. Therefore, a level control system in the deaerator is needed in order to maintain the stability of the boiler feedwater supply. However, to get a good control performance, the controller tuning is required. In this study, the PI controller with feedback feedforward structure is used. Tuning parameters are obtained by using the direct synthesis method where the value of the proportional gain is 0.69 and the integral time is 28.95. Other than that, the feedforward tuning parameters are obtained by the feedforward equation where the value of the feedforward gain is 0.0001, the lead time constant is 28.95, and the lag time constant is 48.48. The controller performance is determined by analyzing the dynamic response graph from the close loop test. Based on the ± 10% setpoint changes test results, the IAE values are 0.000848% and 0.00059%, the maximum overshoot values are 1.52% and 1.86%, and the settling time values are 7130 seconds and 7150 seconds. Furthermore, on the ± 10% disturbance changes test results, the IAE values are 0.442% and 0.443%, the maximum overshoot values are 10.83% and 10.82%, and the settling time values are 6050 seconds and 6060 seconds.The abstract should summarize the contents of the paper and should contain at least 70 and at most 200 words. It should be set in 9-point font size, justified and should have a hanging indent of 2-centimenter. There should be a space before of 12-point and after of 30-point.

1 INTRODUCTION

Deaerator is a mechanical device used in a power plant to remove gases such as O2 and CO2 which are dissolved in condensate water. Besides, the deaerator also functions as a preheater boiler feedwater. The O2 and CO2 gases separation is carried out to prevent the formation of oxides and carbonic acid compounds that can contribute to the boiler pipes corrosion, so it helps to reduce the operation and maintenance costs. Deaerator works based on the nature of oxygen. As an increase in the temperature, the solubility in the water decreases. In that condition, the volume of water decreases, so a water level control in the deaerator is needed to maintain the supply of boiler feedwater and optimize the gases release process. A 350MW coal fired power plant in Indonesia uses a PI controller with a feedback feedforward control loop as a level control in the deaerator. This control loop is known to be more able to adjust load changes and disturbances that affect the dynamics of the system when compared to the feedback control loop. This is because a closed-loop system that only has a feedback structure may not necessarily have stability.

The PI controller requires an adjustment of the gain parameters namely proportional gain ("K" _"p") and integral gain ("K" _"I"). These parameters are determined by the tuning process. There are several tuning methods to get the PID controller parameters. With the right tuning method, the performance of the control system can be improved. Otherwise, improper tuning methods will only worsen the performance of the control system. The performance of the control system will be known from the system response specifications, including steady state, maximum overshoot, settling time, peak time, and rise time.

Because this power plant is still using trial and error as a tuning method, on this occasion tuning will be done using the Direct Synthesis (DS) method by modeling the system using Aspen HYSYS software.

2 PI CONTROLLER

PI controller is a form of feedback control that has

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simple and easy to understand algorithm, it is often applied to many plants in the industry. In a PI control includes Proportional (P) and integral (I) as a basic characters or parameters. Proportional control action has the advantages of an advance and stable control rise time while integral control action has the advantage of minimizing errors. These parameters are used to form a control by determining the transfer function equation which is a representation of a mathematical comparison between input and output in a control system. The PI controller transfer function in the Laplace domain is mentioned as follows.

$$\mathrm{G_{PI}(s) = K_p}\ \left(1 + \frac{1}{\tau_{if}s}\right) \qquad (1)$$

$\mathrm{G_{PI}}$: PI controller gain
$\mathrm{K_p}$: proportional gain
τ_i : integral time constant

3 FEEDBACK FEEDFORWARD CONTROL LOOP

A feedback control system is the process of measuring the output of a system compared to a certain standard. The feedback control loop works by measuring the process variable, comparing it to the desired value (setpoint), and the difference between the two (error) is used as a manipulated variable to reduce the difference. While a feedforward control system detects the disturbance to anticipate or correct the system before the output (process variable) got affected by the disturbance. In general, a feedforward controller cannot be used alone. The feedback feedforward control system is shown by Figure 1.

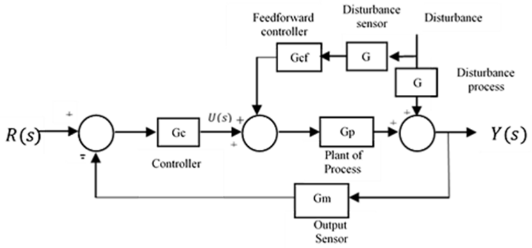

Figure 1: Block Diagram of Feedback Feedforward Control.

Deaerator level control system aims to maintain the level of boiler feedwater in the deaerator remains stable around the setpoint value. Deaerator level control system using feedback feedforward control loop includes three measurement input values (three-element:

a. Deaerator level
b. Boiler feedwater
c. Condensate water

The boiler feedwater and condensate water elements act as feedforward control to prevent the rising feedwater level in the deaerator. The feedforward control will reduce or eliminate the effect of the disturbance in the system, while the feedback control is a simple close loop system that responds to changes in the setpoint. A feedback feedforward control gives a flexibility to the control instruments in determining the required control action. Besides, this method also makes the actuator work effortless.

4 DIRECT SYNTHESIS TUNING

The direct synthesis method is used to determine the parameters of PI controllers. The method gives significant load disturbance rejection performance. This method can be used for the wide variety control processes, including the delay time with a first-order system, a second-order system, an integrator system, and a non-minimum phase system. DS-based controller can be tuned in continuous or discrete time, avoid ringing, eliminate offset, and provide a high level of performance for set-point changes. The direct synthesis method has a simple equation for the controller tuning as shown in equation (2) and (3).

$$K_p = \frac{1}{\mathrm{K}} \frac{\tau}{\tau\mathrm{c}+\theta} \qquad (2)$$

$$\tau_i = \tau \qquad (3)$$

τ : process time constant
K: static process gain
θ : dead time

5 PROCESS MODELING

The first step before simulating a level control is by modeling the behavior of the operating unit deaerator. Aspen HYSYS software is used as a media for modeling and simulating the control system.

Steady-state modeling is the initial step of the simulation before adding control. Modeling begins with the selection of deaerator as an operating unit and placement of input and output streams to regulate system connectivity. The process model is obtained by the actual plant conditions, P&ID and operational data required. So that the modeling is shown in Figure 2.

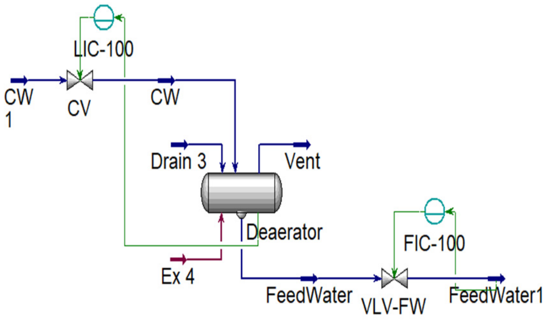

Figure 2: Deaerator Level Control P&ID.

6 CONTROL SYSTEM SIMULATION

Simulation of the control system is necessary to determine the tuning parameters and the performance of level control, by simulating an open loop and close loop system.

6.1 Open Loop

The control system is simulated at a certain time to represent the achievement of steady conditions after changes of manipulated variable occur. An analysis is performed by determining the parameters of FOPDT (First Orde Plus Dead Time) approach K, τ, and θ after an open-loop response graph from the control system obtained. FOPDT is a mathematical model for obtaining a transfer function of a process which is then used to determine the PI tuning parameters "K" _"p" and "τ" _"i" (Ariyanto, 2011). To obtain the transfer function, it is approximated by the PRC equation of Cecil L. Smith shown in the following equation (4), (5), and (6) (Smith and Armando, 1985)

$$K = \frac{\Delta}{\delta} \tag{4}$$

$$\tau = 1{,}5\ (t_{63\%} - t_{28\%}) \tag{5}$$

$$\theta = t_{63\%} - \tau \tag{6}$$

K : gain steady state
Δ : output variable changes
δ : input variable changes
t63% : response time to reach 63% of the output variable
t 28%: response time to reach 28% of the output variable
τ : time constant

Determination of K_p and τ_i using the Direct Synthesis tuning method can be done through the following steps.

a. Modelling the system to obtain the characteristics of a process
b. Create an open-loop system response by changing the controller mode to manual. And change the value of the controller output of ± 5% of the specified value
c. Analyze the open-loop response graph to get the FOPDT parameters in the form of K, τ, and "θ" value
d. Determine the Direct Synthesis tuning parameters in the form of value Kp and τ if .

Because of the feedforward structure in the feedback feedforward control loop, so that feedforward tuning required. Determination of feedforward tuning parameters in the form of value where K_f , τ_1 , and τ_2 is shown in equation (7), (8), and (9).

$$K_f = \frac{K_d}{K_t\, K_v\, K_p} \tag{7}$$

$$\tau_1 = \tau_p \tag{8}$$

$$\tau_2 = \tau_d \tag{9}$$

K_f: feedforward gain
τ_1: lead time constant
τ_2: lag time constant

6.2 Close Loop

The control system is simulated to get the control performance from the response graph towards setpoint and disturbance changes by analyzing three parameters below (Ogata, 2010).

a. Settling Time
The settling time (t_s) is the time required for the step response to enter the criteria area of 2% or 5% of the final value.

b. Maximum Overshoot
Maximum overshoot (MO) is the peak value of the response curve that can be determined by following equation.

$$\%MO = \frac{c(t_p)-c(\infty)}{c(\infty)} \times 100\% \tag{10}$$

c. Integral Absolute Error
Integral Absolute Error (IAE) is the sum of the error value of the response curve by conditioning the error to an absolute value. IAE can be determined by following equation (Singh, 2009).

$$IAE = \int_0^{\infty} |SP(t) - CV(t)|\, dt \tag{11}$$

7 RESULTS AND DISCUSSION CONTROL SYSTEM SIMULATION

7.1 Open Loop Test based on Control Valve Changes

Open-loop simulation aims to find the transfer function of the process. Response graph is obtained by changing 5% of the valve position in 1020 minutes duration shown in Fig. 3. The controller involved is the level indicator control (LIC) as a feedback feedforward control. Where liquid percent level is a process variable and inlet condensate water valve is a controller output which operates as a control valve.

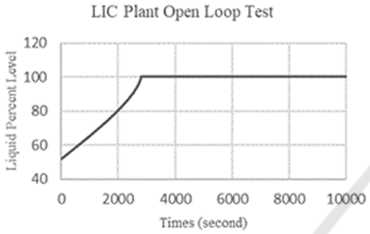

Figure 3: Open Loop Response Graph to 5% CV Changes.

Furthermore, with an approach through equation (2), (3), and (4), the value of FOPDT parameters are shown in table 1.

Table 1: FOPDT Plant Parameters.

Instrument	Parameter		
	K	τ (min)	θ (min)
LIC	10	28.95	0

Feedback tuning parameters are obtained through equation (5) and (6) where K_p is 0.69 and τ_I is 28.95.

7.2 Open Loop Test based on Disturbance Changes

FOPDT parameters from disturbance changes are needed to determine the feedforward tuning parameters. Response graph is obtained by changing 5% of the outlet feedwater flowrate in 1020 minutes duration shown in Fig. 4. The changes made from FIC as an additional instrument for disturbance utility which controls the value of the disturbance.

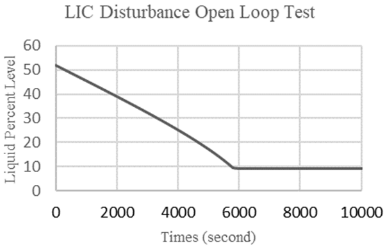

Figure 4: Open Loop Response Graph to 5% DV Changes.

Furthermore, with an approach through equation (2), (3), and (4), the value of FOPDT parameters are shown in table 2.

Table 2: FOPDT Disturbance Parameters.

Instrument	Parameter		
	K	τ (min)	θ (min)
LIC	0.0007	48.48	0

Feedforward tuning parameters are obtained through equation (7), (8), and (9) where K_f is 0.0001, τ_1 is 28.95, and τ_2 is 48.48.

7.3 Close Loop Test based on Setpoint Changes

Close loop simulation aims to specify the control performance based on setpoint changes refers to the use of known tuning parameters. Analysis of LIC feedback feedforward control responses based on ±10% setpoint changes are respectively shown in Figure 5 and Figure 6.

Based on Figure 5 and Figure 6 it can be seen that the feedback feedforward level control can respond to the setpoint changes. The process variable value tracks the setpoint changes which start at 50% to 55% and 45% level. In achieving setpoint value, the control process took a certain time. The performance of feedback feedforward level control with Direct Synthesis tuning can be assessed by calculating settling time, maximum overshoot (MO), and integral absolute error (IAE). These three parameters of quantitative response analysis are shown in table 3.

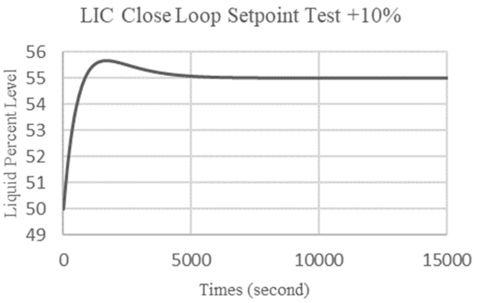

Figure 5: Close Loop Response Graph to +10% SP Changes.

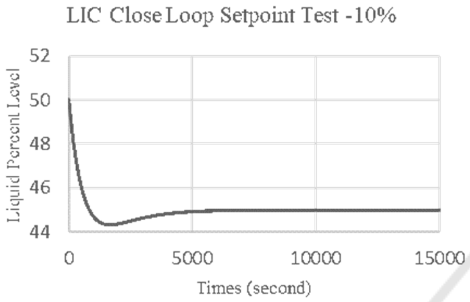

Figure 6: Close Loop Response Graph to -10% Changes.

Table 3: Close Loop Test based on ±10% Setpoint changes.

Parameters	**Units**	**Setpoint Changes**	
		+10%	**-10%**
t_s	seconds	7130	7150
MO	%	1.52	1.86
IAE	%	0.000848	0.000591

Based on table 3. the feedback feedforward level control had a certain time to achieve the given setpoint. In this close loop test the time required for a process variable to reach the setpoint is nearly close, respectively 7130 seconds and 7150 seconds on +10% and -10% setpoint changes. It also showed that the control response remains stable based on a low maximum overshoot value.

7.4 Close Loop Test based on Disturbance Changes

Close loop simulation aims to specify the control performance based on disturbance changes refers to the use of known tuning parameters. Analysis of LIC feedback feedforward control responses based on ±10% disturbance changes are respectively shown in Figure 7 and Figure 8.

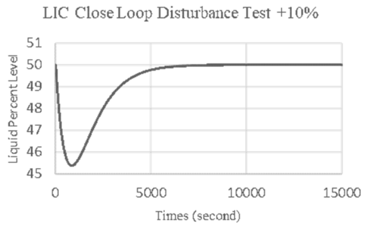

Figure 7: Close Loop Response Graph to +10% DV changes.

Based on Fig. 7 and Fig. 8 it can be seen that the feedback feedforward level control can respond to the disturbance changes. The process variable value tracks the level setpoint while the disturbance was given to the control process. In achieving setpoint value, the control process took a certain time. The performance of feedback feedforward level control with Direct Synthesis tuning can be assessed by calculating settling time, maximum overshoot (MO), and integral absolute error (IAE). These three parameters of quantitative response analysis are shown in table 4.

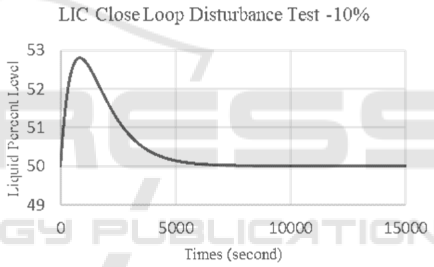

Figure 8: Close Loop Response Graph to -10% DV Changes.

Table 4: Close Loop Test based on ±10% Disturbance changes.

Parameters	**Units**	**Disturbance Changes**	
		+10%	**-10%**
t_s	seconds	6050	6060
MO	%	10.82	10.82
IAE	%	0.442	0.443

Based on table 4. the feedback feedforward level control had a high maximum overshoot value in overcoming the given disturbance. When the outlet feedwater flow rate increased, the level value will immediately drop. However, the controller returns the process variable value to the desired setpoint. In this close loop test the time required for the process variable to reach the setpoint is nearly close, respectively 6050 seconds and 6060 seconds on +10% and -10% disturbance changes.

8 CONCLUSIONS

After analyzing the deaerator level control response, it can be concluded that using the direct synthesis as a tuning method for the feedback feedforward control can produce a control that able to track the setpoint changes and handle the disturbance in the system.

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