Best Control Structure for Water Level with Regulated Discharge Flow

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Abstract— **This paper is to investigate the best control structure and tuning parameters for controlling the water level of the trainer system that located at the DCS laboratory UiTM Shah Alam. In this work, the parameter of the controller is adjusted using Ziegler Nichols tuning method. The best control structure is analyzed by considering the rise time, settling time, overshoot and steady state error. The result showed that the water level integrating process can best control using Proportional + Integral + Derivative with parallel structure.**

Keywords- water level, control structure, controller tuning, regulated discharge flow, Ziegler-Nichols(ZN)

I. Introduction

Generally, water level control systems that have a regulated exit flow stream do not naturally settle at steady-state operating level and can be remarkably challenging to control. Hence, many researches had been conducted to study and improve the system [1]–[13]

Amongst, PID controller is the most commonly used controller for the process because of the possibility of making PID controllers with automatic tuning, automatic generation of gain and continuous adaption [2]–[11]. Furthermore, it is well understood by many operational, technical and maintenance personnel. However, PID is not always used in the best way in which there is often poorly tuned. In fact, the derivative action is mostly ignored due to the difficulty of tuning three parameters simultaneously.

The objective of this project is to study the best control structure and parameters for water level with regulated discharge flow. The project is focused on the closed loop performance by using Ziegler-Nichols tuning method for integrating first order plus time delay process model. The ideal, parallel and alternative control structures [11] are used for comparison. In addition to that, both transient and steady-state responses are analyzed to estimate the dynamic performances of the process.

II. Process Description

The process plant shown in Figure 1 is a system located at DCS laboratory, UiTM Shah Alam used for water level control system and measurement. The process plant is equipped with the pressure regulator and pumps. The pressure regulator operated of output 0 -10Vdc proportional to the fluid level inside the tank. It is used to measure the water level in the main tank (T-03). The water level is measured and controlled in the main tank with maximum capacity of 500mmH2O. In this process, water from reservoir tank (T-01) enters the main tank using a pump (PCV-01). The controller is used to control the rate of the water delivered by the pump so that the water level is within the desired target.

Figure 1. Water level Trainer System

The piping & instrumentation drawing for the process plant is as shown in Figure 2. The water level in the main tank is measured using differential pressure technique in which the differences in pressure reading determine the level of the water in the tank.

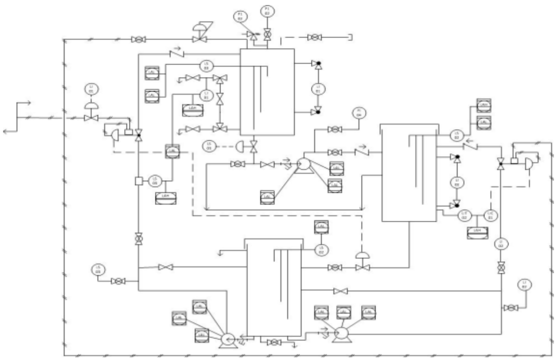

Figure 2. Piping & Instrumentation Diagram

III. PROCESS MODEL

In general, the mathematical model for integrating process is as shown in (1) where Tdd is the process dead time and K is the process gain.

$$G(s) = \frac{Ke^{-T_{dd}s}}{s} \qquad (1)$$

The two important parameters in (1) can be obtained using method [7] as shown in Figure 3.

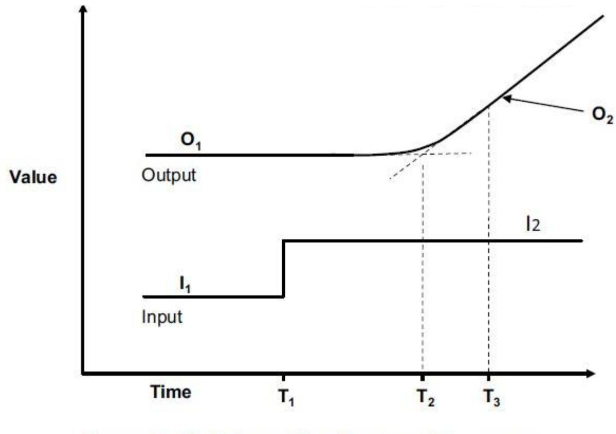

Figure 3. Response of integrating process

$$Integrating\ gain = \frac{O2 - O1}{(I2 - I1)(T3 - T2)} \qquad (2)$$

$$Dead\ Time = T2 - T1 \qquad (3)$$

In this work, the open loop test was done experimentally using the following settings:

- Set the set point to 300mmH20
- Open manual valve V-19
- Start the pump P01
- PCV-01 is set to 10%
- PCV-01 is changed to 11% (When the process is stabilize for about 2 to 3 minutes)

In this work, control valve PCV-01 is a valve to control water into the main tank. Along this experiment, the HV-10 (discharge valve) is shut and HV-14 fully open.

IV. PID CONTROLLER

The different structure of PID controller will come with the different implications on controller tuning [9]. The equation for parallel form PID [10] is given in (4).

$$G(s) = \frac{U(s)}{E(s)} = Kp\left(1 + \frac{1}{Tis} + Tds\right) \qquad (4)$$

Where Kp is the controller gain, Ti is the integral time constant and Td is the derivative time constant. The control structure for parallel [9] is shown in Figure 4.

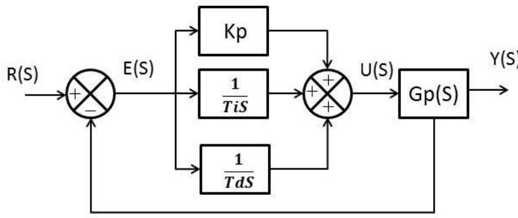

Figure 4. Parallel PID control structure

P, I and D parts are separated and connected in parallel is the main characteristic of the parallel type. If the derivative action is use properly it can improve the performance by increase the stability and help to maximize the integral gain [11]. The transfer function for Ideal form PID [11] is shown in (5) and the control structure for ideal [11] is shown in Figure 5.

$$G(s) = \frac{U(s)}{E(s)} = Kp\left(1 + \frac{1}{Tis} + \frac{Tds + 1}{1 + \alpha Tds}\right) \qquad (5)$$

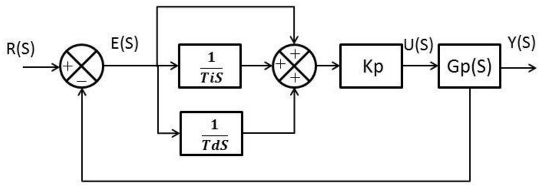

Figure 5. Ideal PID control structure

Transfer function for the alternative PID control structure [11] is as shown in (6) and the control structure is shown in Figure 6. In this structure, the error signals drive the proportional and integral elements [11].

$$G(s) = \frac{U(s)}{E(s)} = Kp\,(1 + \frac{1}{Tis} + \frac{Kp\left[1 + \frac{1}{Tis}\right]}{1 + Kp\left[1 + \frac{1}{Tis} + \frac{Tds + 1}{1 + \alpha Tds}\right]} \qquad (6)$$

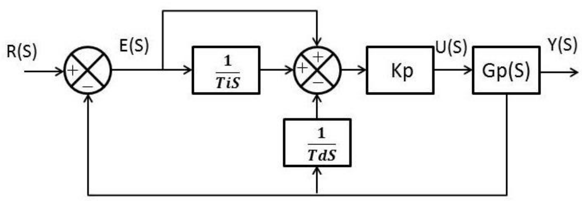

Figure 6. Alternative PID control structure

In this work, the control structure shown in Figure 4, Figure 5 and Figure 6 are implemented to the process using PI and PID in which the performance of the controllers to the process dynamic are compared.

V. PID TUNING

In general, the proportional gain (Kp) will effect of reducing the rise time and will minimize but never eliminate the steady-state error. Whereas, an integral time constant (Ki) will make transient response slower and eliminating steady state error while derivative time constant (Kd) will increase the stability, improve transient response and reduce the overshoot. The effects of Kp, Ki and Kd of PID controllers on a closed-loop control system are summarized in Table I.

TABLE I. EFFECTS OF PROPORTIONAL, INTEGRAL AND DERIVATIVE ACTIONS

Controller	***Rise time***	***Settling time***	***Overshoot***	***Steady state error***
Kp	Decrease	Small change	Increase	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small change	Decrease	Decrease	No change

In this work, Matlab Simulink is used to simulate the process dynamic response in which the controller parameters are adjusted using Ziegler-Nichols tuning method.

The best controller type with the best control structure and parameters is chose by comparing the process dynamic performance in terms of settling time, rise time, percent overshoot and steady state error [12]. Normally, the process dynamic performance is best described as follows [11], [12]:

- Reduce in settling time
- Reduce in rise time
- Small steady state error
- Minimum percent overshoot

VI. RESULTS AND DISCUSSION

The open loop response curve for the process is as shown in Figure 7. The First Order Plus Dead Time (FOPDT) integrating model of the process is as shown in (7) in which the process dead time is found as 44 sec and process gain is equal to 1.078.

$$G(s) = \frac{1.078e^{-44s}}{s} \qquad (7)$$

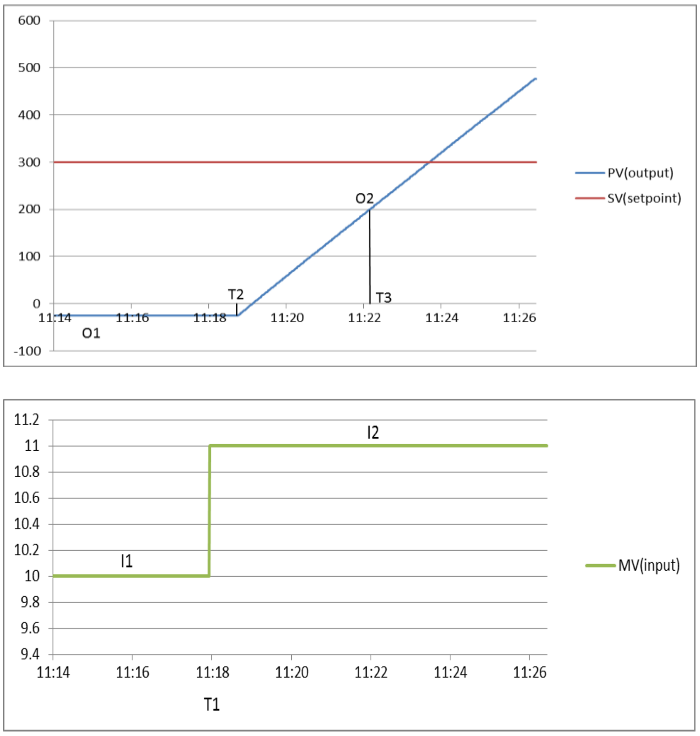

Figure 7. Open loop test process response

The calculation for gain,k and dead time, Td is as shown below:

$$Integrating\ gain, k = \frac{O2 - O1}{(I2 - I1)(T3 - T2)}$$

$$k = \frac{200.2 - (-25.2)}{(11 - 10)(11{:}22{:}30 - 11{:}19{:}01)}$$

$$k = \frac{225.4}{(1)(209)}$$

$$k = 1.078$$

$$Dead\ time, Td = T2 - T1$$

$$Td = 11{:}19{:}01 - 11{:}18{:}17$$

$$Td = 44s$$

The plot of the process response by ZN tuning is shown at Figure 8 to Figure 10 for PI and Figure 14 to Figure 16 for PID while the process response by ZN fine tuning is shown at Figure 11 to Figure 13 for PI and Figure 17 to Figure 19 for PID. All this plot are obtained by using Matlab Simulink.

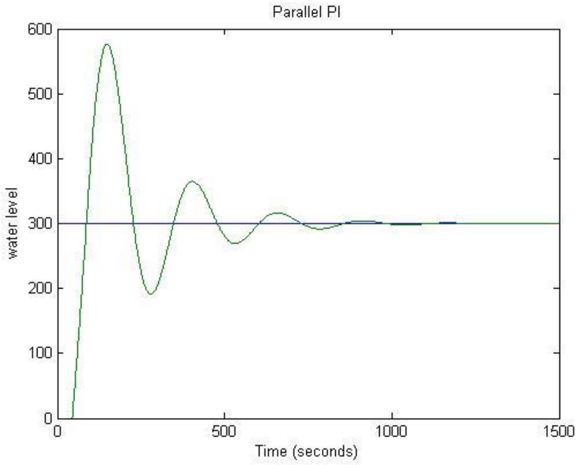

Figure 8. Parallel PI(ZN tuning)

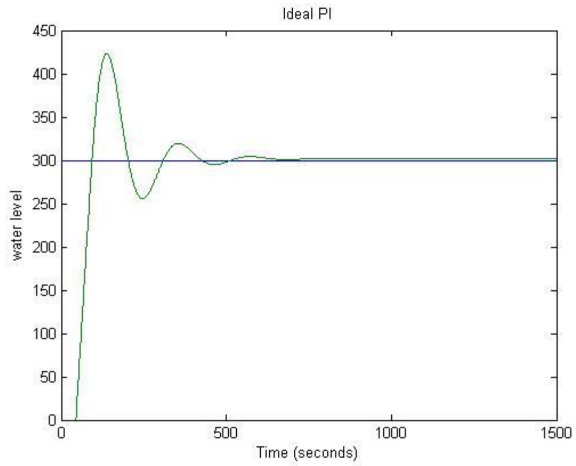

Figure 9. Ideal PI (ZN tuning)

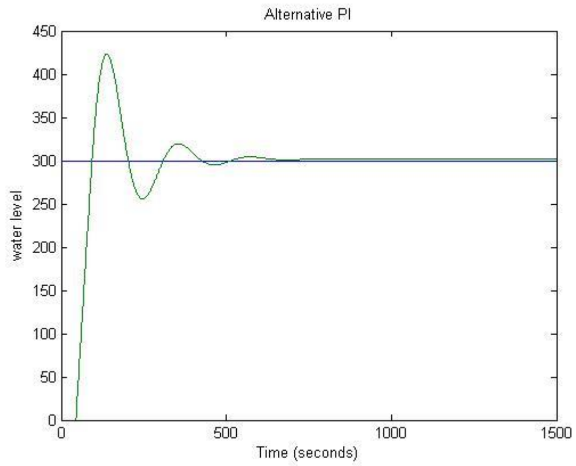

Figure 10. Alternative PI (ZN tuning)

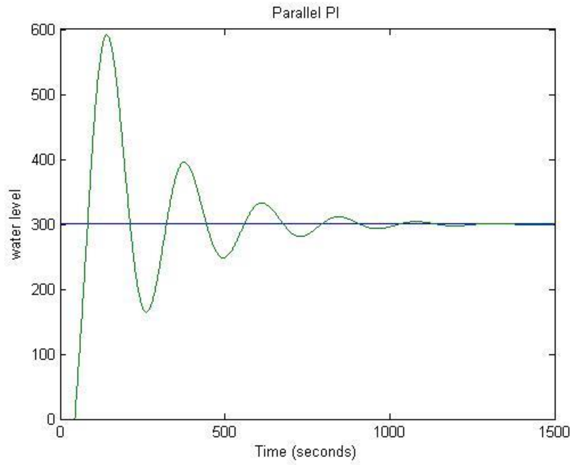

Figure 11. Parallel PI (ZN fine tuning)

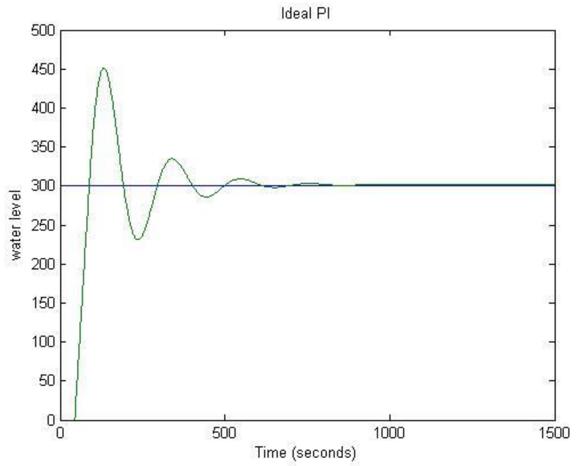

Figure 12. Ideal PI (ZN fine tuning)

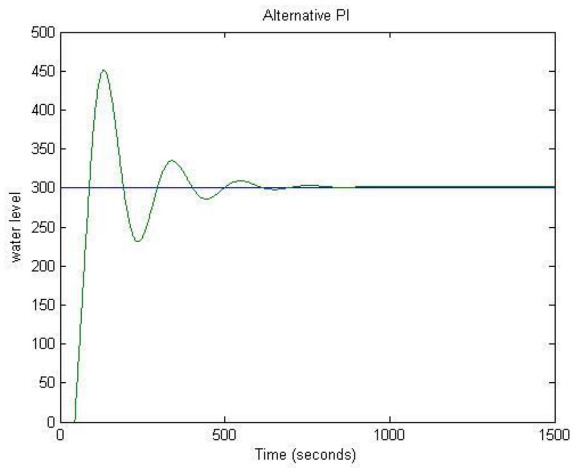

Figure 13. Alternative PI (ZN fine tuning)

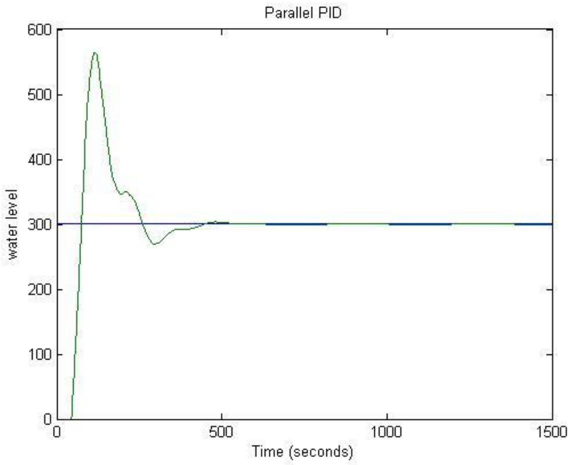

Figure 14. Parallel PID (ZN tuning)

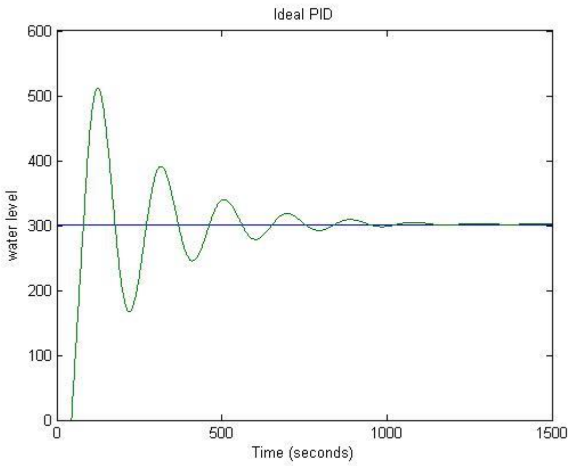

Figure 15. Ideal PID (ZN tuning)

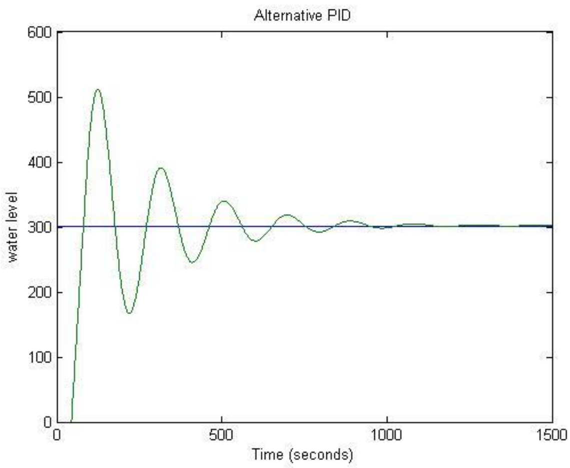

Figure 16. Alternative PID (ZN tuning)

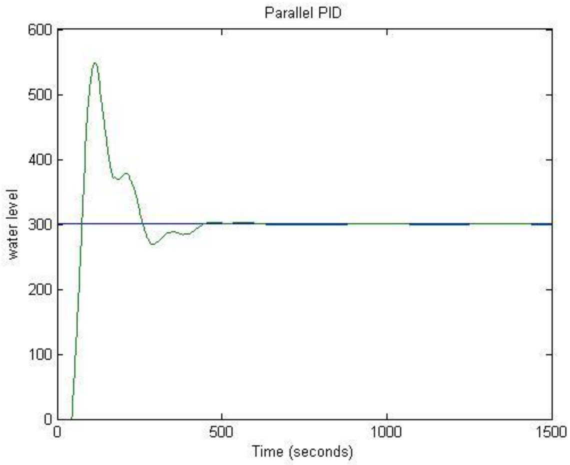

Figure 17. Parallel PID (ZN fine tuning)

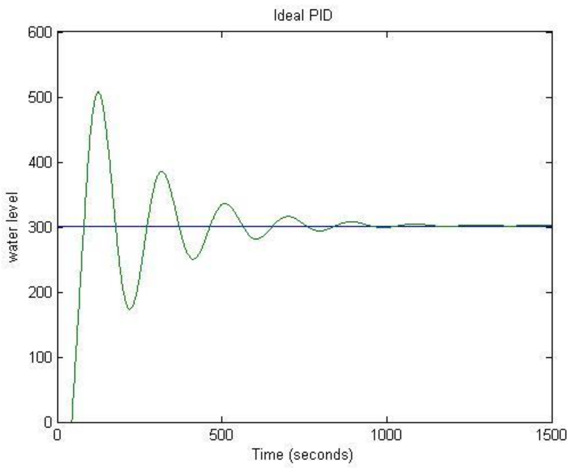

Figure 18. Ideal PID (ZN fine tuning)

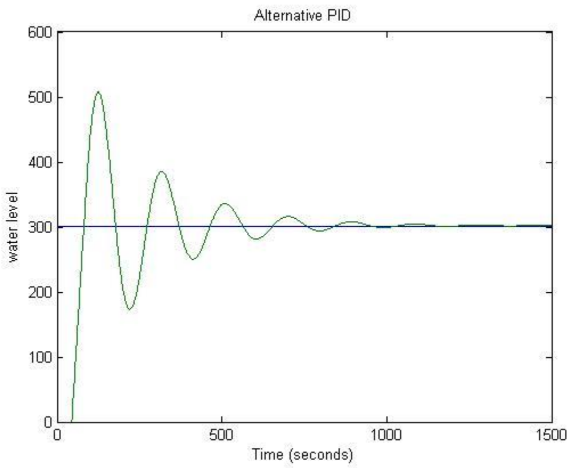

Figure 19. Alternative PID (ZN fine tuning)

Table II shows the list of parameters that are used in this project. The ZN tuning method is used to find the values of Kp, Ki and Kd. The parameter of ZN tuning then adjusted by following the theory that shown in Table I to improve the result on rise time, settling time, overshoot and steady state error.

TABLE II. LIST OF PARAMETERS

ZN Tuning Method	*Kp*		*Ki*		*Kd*	
	PI	*PID*	*PI*	*PID*	*PI*	*PID*
Before	0.019	0.0253	1.297e-04	2.875e-04	-	0.5566
Fine parameter	0.021	0.025	1.299e-04	2.87e-04	-	0.6

TABLE III. PROPORTIONAL INTEGRAL (PI) – ZN TUNING

Kp = 0.019 Ki = 1.297e-04

Structure	*Rise time*	*Settling time*	*Overshoot*	*Steady state error*
Parallel	33.9949	817.1493	92.0981	0
Ideal	39.1410	477.5387	40.3331	1.6
Alternative	39.1410	477.5387	40.3331	1.6

TABLE IV. PROPORTIONAL INTEGRAL (PI) – ZN FINE TUNING

Kp = 0.021 Ki = 1.299e-04

Structure	*Rise time*	*Settling time*	*Overshoot*	*Steady state error*
Parallel	31.4400	983.0870	97.2264	0
Ideal	35.4048	569.8717	49.8445	1.5
Alternative	35.4048	569.8717	49.8445	1.5

From the Table III and Table IV, ideal and alternative is the best structures because it has small settling time and overshoot. Parallel have the best rise time and does not have steady state error but the difference value of the rise time between parallel and ideal is very small. Even though ideal and alternative have steady state error but the value is very small. From the Table 3, the value of Kp and Ki is increased to improve the rise time and the steady state error but the overshoot and settling time cannot be improve because in PI there is no Kd. Kd is use for reduce the overshoot and settling time. By changing the value of Kp and Ki the value of rise time and steady state error become smaller. The result for ideal and alternative is same because without the derivative this structure will have no difference.

TABLE V. PROPORTIONAL INTEGRAL DERIVATIVE (PID) – ZN TUNING

Kp = 0.0253 Ki = 2.875e-04 Kd = 0.5566

Structure	*Rise time*	*Settling time*	*Overshoot*	*Steady state error*
Parallel	24.8195	413.7419	88.1982	0
Ideal	29.4056	905.1185	69.3539	2
Alternative	29.4056	905.1185	69.3539	2

From the Table V it can be concluded that the parallel control structure to the process is the best because it contribute to minimum rise time, settling time and do not have steady state error. The value of rise time and settling time for ideal and alternative is very big but overshoot have small value. The steady state error for three structure is very small and can be considered as dynamic response criteria.

TABLE VI. PROPORTIONAL INTEGRAL DERIVATIVE (PID) – ZN FINE TUNING

Kp = 0.025 Ki = 2.87e-04 Kd = 0.6

Structure	*Rise time*	*Settling time*	*Overshoot*	*Steady state error*
Parallel	25.0409	427.0982	83.0197	0
Ideal	29.7584	820.6432	67.8311	2
Alternative	29.7584	820.6432	67.8311	2

From the Table VI, the value of Kp and Ki is change but in small value it is because the rise time and steady state error from Table V shows the best value. Thus, to decrease the overshoot and the settling time the value of Kd need to be increase. The value of Kd is increased from 0.5566 to 0.6. From Table VI, the rise time change but in small value and the steady state error maintain same as in Table V. This is because the value of Kp and Ki used in the Table V and Table VI is almost same and only have very small difference value. The small changes in Kp and Ki is made according to the main aim which is to reduce the overshoot and settling time.

By comparing the best structures using PI method, it shows that ideal and alternative by using ZN tuning has the best structure. They have minimum settling time, overshoot and small steady state error. Parallel structure that use parameter ZN fine in PID tuning is the best structure with rise time, settling time and do not have steady state error.

VII. CONCLUSION

The best control structure and tuning parameters for water level integrating process is successfully studied. From the results obtained, it is found that PI controller gives the best performance indication when using alternative or ideal control structure to the process. In comparison with parallel control structure, PID controller gives the better performance than PI controller. Amongst, PID controller with parallel control structure is the best candidate for controlling water level of the trainer system that located at the DCS laboratory UiTM Shah Alam.

ACKNOWLEDGMENT

Author likes to thank the Faculty of Electrical Engineering, UiTM and project supervisor for helping in completing this project.

REFERENCES

[1] I. S. Isa, B. C. C. Meng, Z. Saad, and N. a. Fauzi, "Comparative study of PID controlled modes on automatic water level measurement system," *Proc. - 2011 IEEE 7th Int. Colloq. Signal Process. Its Appl. CSPA 2011*, pp. 237–242, 2011.

[2] W. S. Levine, *The Control Handbook*. CRC Press, 1996.

[3] L. Chen, C. Wang, Y. Yu, and Y. Zhao, "The research on boiler drum water level control system based on self-adaptive fuzzy-PID," *2010 Chinese Control Decis. Conf. CCDC 2010*, pp. 1582–1584, 2010.

[4] M. G. N. M. G. Na, "Auto-tuned PID controller using a model predictive control method for the steam generator water level," *IEEE Trans. Nucl. Sci.*, vol. 48, no. 5, pp. 1664–1671, 2001.

[5] M. Ajmeri, "PI Tuning for Integrating First Order Plus Time Delay Processes," pp. 157–162, 2013.

[6] and H.-R. R.-A. Momenizadeh, I., A. Madady, "A Graphical Approach to Design PI Controller for Integrator plus Dead-Time Processes," pp. 320–325, 2011.

[7] N. Hambali, M. Nazmi, and K. Zaki, "Reformulated Tangent Method of Various PID Controller Tuning for Air Pressure Control," pp. 23–25, 2012.

[8] C. D. William, *Fundamentals of Industrial Instrumentation and Process Control*. New York: McGraw-Hill, 2005.

[9] T. K. Kiong, Q. G. Wang, and C. H. Chang, *Advances in PID Control*. Springer, 1999.

[10] M. Tajjudin, M. H. F. Rahiman, N. Ishak, R. Adnan, and H. Ismail, "Model Evaluation of a Steam Distillation Process for Steam Temperature Regulation," *2012 Third Int. Conf. Intell. Syst. Model. Simul.*, pp. 431–435, 2012.

[11] Z. Janin, Z. Yusuf, and M. N. Taib, "PID control structure for glycerin bleaching process: A comparative study," *Proc. - 2011 IEEE 7th Int. Colloq. Signal Process. Its Appl. CSPA 2011*, pp. 448–452, 2011.

[12] R. N. Bateson, *Introduction to Control System Technology*, 7th editio. Prentice Hall PTR, 2001.

[13] F. Haugen, "Tuning of PID controllers," in *PID Control*, Tapir Academic Press, 2004, pp. 121–128.

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