Advanced Control Strategies for Level System: The Application of Simulink for PID System

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***Abstract*— Any processes that have dynamics behavior and time delay makes the process difficult to be controlled. However, this type of processes are widely exist in our industries thus makes it important for us to control it regardless of the difficulties faces. The important of control system in today industries have a great impact on the emerging of new tuning method. Despite that, proportional, integral and derivative (PID) controllers still have been used in vast chemical process industries due to their robustness, simplicity and successful practical application. There are many proposed tuning methods for PID controllers to replace the conventional PID controllers. Thus, this paper presents the study of two advanced tuning methods, internal model control (IMC) and direct synthesis (DS) based on PID for controlling level system. The performances for both tuning methods are being compared justify the effectiveness of both tuning method. The selection of the most suitable value of closed-loop time constant is the main concern since it is the essential tuning parameter for enhancing the transient and steady state behavior for the process output. The higher value of time constant results in a better performance. The study shows that DS and IMC produces an identical results. In helping to decide the best tuning method of identical DS and IMC, integral of the absolute value of the error (IAE) has been used. The results showed DS tuning method provide better performance compared to IMC tuning method.**

Keywords*— *Advanced Control Strategies, Direct Synthesis, Internal Model Control, Level System, MATLAB Simulink, Nonlinear System, PID Tuning, Tangent Method.

I. INTRODUCTION

Level control system is important to ensure the smoothness of a process and also to obtain the desired product. This type of control system is widely used in our industries such as chemical industries. Besides, the PID controller has been used for wide range of systems including liquid level system, boilers, liquid storage tank batch chemical reactor and the bottom level manage of distillation column [1].

The real time setup model can be classified as linear and nonlinear models. For controlling the linear process, PI controllers are widely used. However, most of the industries are working on nonlinear delay dominated system in order to control the liquid flow. Because of the dynamics behavior of level system, it is necessary to control the system. Therefore, PID is always being great choice. Although there are other techniques that can supply significant improvements, for many decades, PID controller has continued to be the most used control techniques. Until the last decade, more than 90% of all control loops are PID [2]. Variety of PID tuning for first-order-plus-dead-time system being elaborated in literature for the past few decade including internal model control and synthesis method.

In order to investigate the system's behavior in industries and other field of living, the simulation are the important tools that often being use [3]. The advantages of using simulation is about its safety because if experiments are done on real system it could be hazardous.

II. METHODOLOGY

A. Tuning Methods

The PID tuning method steps are divided into two categories which are

I. Open loop test

Techniques in which a system is operates in open loop and the controller is control in manual mode

II. Closed loop test

Techniques in which a system is operates in closed loop and the controller is control in automatic mode

B. Open loop test

Open loop test was done to get the open loop response curve. The curve obtained was analyzed using Tangent Method (TM) based on the changes of ΔMV. Figure 3.1 shows the open loop response curve for the real time non-self-regulating level system for 10% of ΔMV.

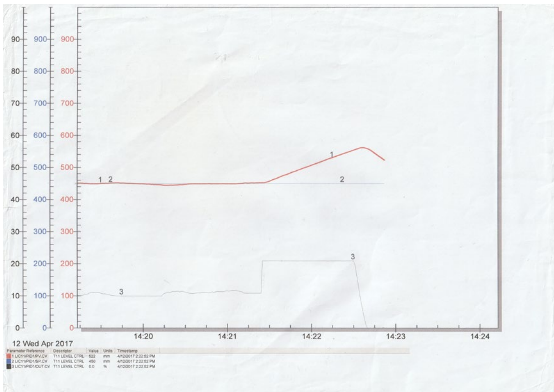

Fig. 3.1: Open loop response curve

From Figure 3.1 it can be seen that the old steady state for the real time non-self-regulating level system was stabled at 40 %. After changes was made such as that ΔMV = 10%, there is an increment on the ΔPV. Optimum value for PID controller were obtained from the response curve by using TM.

Table 3.1: Open loop response curve results

Method	P	T_d (s)	T_c (s)
Tangent Method	1.1	0.0045	0.01

C. Closed loop Test

The present work is intended to study the performance between two methods which are (i) DS and (ii) IMC.

i. IMC Method

$$G_c = \frac{\tau}{k\tau_c} + \frac{1}{k\tau_c s} \qquad \text{Eq. 1}$$

ii. DS Method

$$K_c = \frac{\tau}{k(\tau_c + \theta)} \qquad \text{Eq. 2}$$

All of the equations above were compared with Equation 3.

$$PI = k_c\left(1 + \frac{1}{\tau_I s}\right) \qquad \text{Eq. 3}$$

Thus, the equations for calculating the PID controller obtained from the equations are as shown in Table 3.2

Table 3.2Equations used for PID controller calculations

Tuning method	P	I
DS	$K_c = \frac{\tau}{k(\tau_c + \theta)}$	$\tau = \tau_I$
IMC	$K_c = \frac{\tau}{k\tau_c}$	$\tau = \tau_I$

Different selected values of τ_c are shown in Table 3.3 by following the rules as shown below.

1. $\frac{\tau_c}{\theta} > 0.8 \text{ and } \tau_c > 0.1\tau$
2. $\tau > \tau_c > \theta$
3. $\tau_c = \theta$

Table 3.3Different selected τ_c values

Tuning	DS/IMC
1st	2.22 1 0.5
2nd	0.009 0.007 0.006
3rd	0.01

Thus, the values of PID controller listed in Table 3.4 were calculated by using the equations shown in Table 3.2. The values for the calculations were obtained from the selected values of τ_c as shown in Table 3.3 and open loop response curves data as shown is Table 3.1.

Table 3.4Calculated PID Controller values

Tuning	DS		IMC	
	P	I	P	I
1st	0.004087 0.00905 0.0180	0.01	0.004095 0.009091 0.01818	0.01
2nd	0.6734 0.7905 0.8658	0.01	1.0101 1.2987 1.5152	0.01
3rd	1.0101	0.01	2.02	0.01

D. *Simulation*

The implementation of IMC and DS tuning method result in feedback system. The simulation was done in MATLAB to illustrate the performance for both methods.

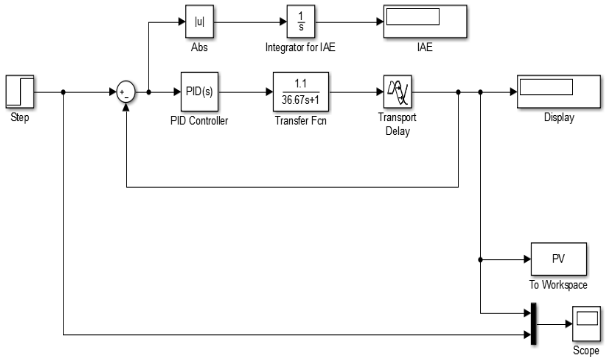

Fig. 3.2: Simulink block diagram for IMC and.

III. RESULTS AND DISCUSSION

A. *The effects of* τ_c *to the level system performance*

From all tuning values of DS and IMC methods, the performances were compared. The performances were analyzed from the response curve obtained from the simulation of those values.

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i. IMC response curve

Figure 3.3 compares the IMC tuning at three different value of τ_c by following the first rule.

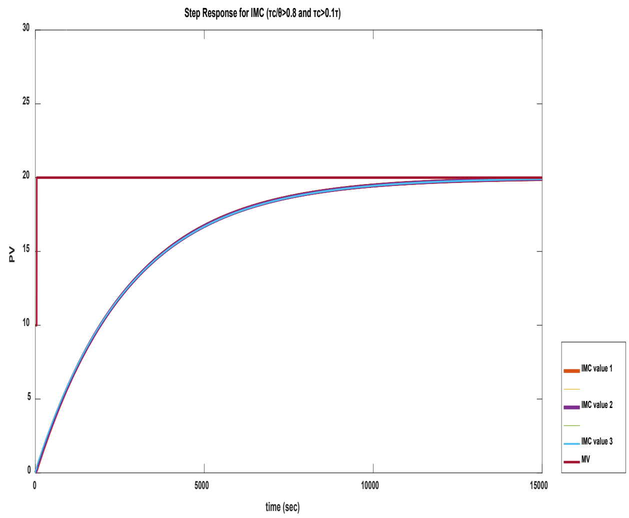

Fig. 3.3: Step Response Curve of IMC

Based on the response curve in Figure 3.3 produced by three different value of τ_c, it was determined that the second value of IMC tuning gives the best performance. It has fast rise time and settling time compared to the third value which is move slow towards the new set point. Although the first value gives fast rise time than second value and their settling time that are quite similar, it shows that the response for first value is oscillated. The value of IAE for first, second and third value are 179.65, 178.72 and 177.05 respectively. Thus, among the three values, the second value was chosen as the best value for this tuning because of best rise time and settling time and IAE of 178.7.

Figure 3.4 compares the IMC tuning at three different value of τ_c by following the second rule.

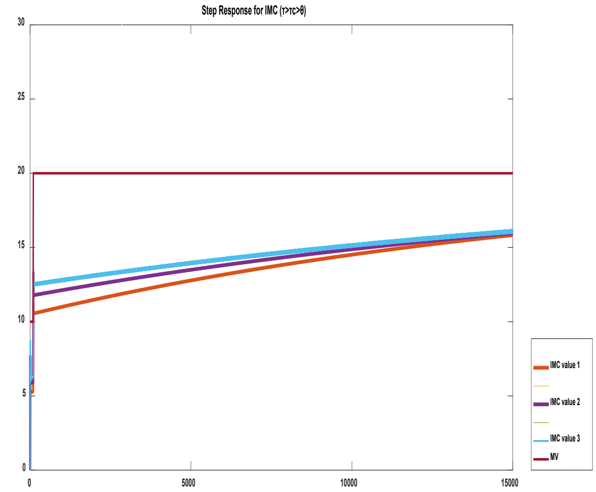

Fig. 3.4: Step Response Curve of IMC

Based on the response curve in Figure 3.4 produced by three different value of τ_c, it was determined that the first value of IMC tuning gives fast rise time and settling time compared to the second and third value of this IMC tuning. The third value gives an oscillatory response curve as well as slow rise time and settling time. The second value has moderate rise time among the tuning values however it produce fast settling time than the third value. The value of IAE for first, second and third value are 87.88, 76.64 and 69.94 respectively. Therefore, the first value gives the best performance with fast rise time, settling time and IAE equal to 87.88

Figure 3.5 shows the comparison of the best tuning values from the first and second rules including the third rule. The third rule has been tuned using only one value of τ_c since the value of τ_c should be equal to time delay according to the third rule.

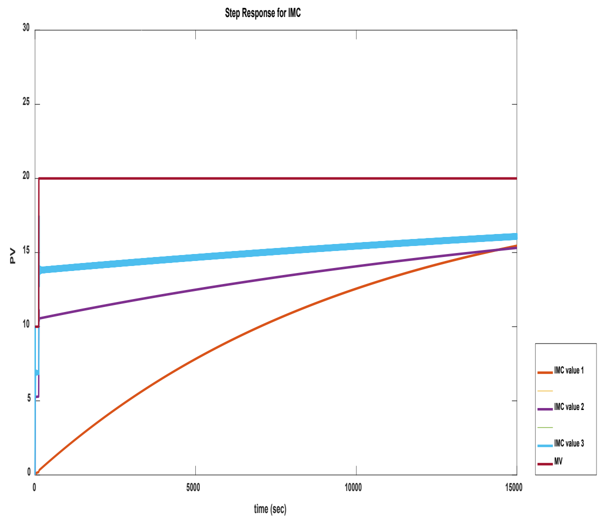

Fig. 3.5: Step Response Curve of IMC

The second value from first tuning, first value from second tuning and the value from third tuning were compared to find the best tuning among the best. It was found that the second value from the first tuning gives the best performance. It has fast rise time and settling time compared to the others. The first value from the second tuning give moderate rise time and value are 178.72, 87.88 and 58.08 respectively. According to the criteria, the first value is the best tuning which give the best performances.

i. DS response curve

Figure 3.6 compares the DS tuning at three different value of τ_c by following the first rule.

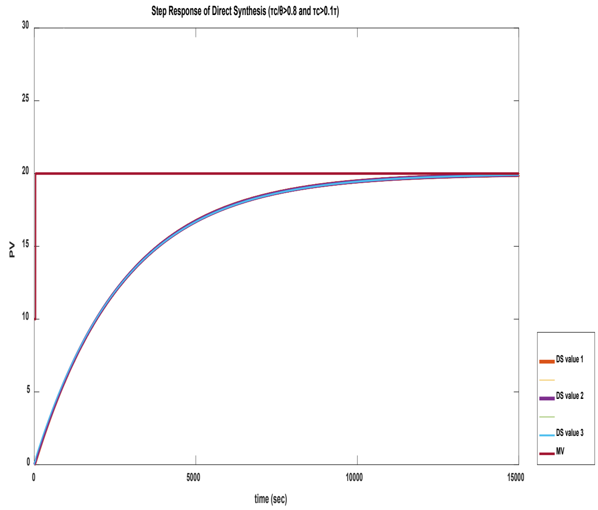

Fig. 3.6 Step Response Curve of DS

Same goes to the results in IMC first rule, Figure 3.6 shows the response curve of DS for all three different value of τ_c. The second value gives moderate rise time at the beginning however it is become faster with time and eventually has the fastest settling time. Even though the first value has the fastest rise time at the beginning and identical settling time with second value, it has an oscillatory response curve. The third value gives fast rise time at the beginning and become slower with time as well as slow settling time towards the new set point compared to the other two values. The value of IAE for first, second and third value are 179.65, 178.73 and 87.88 respectively.

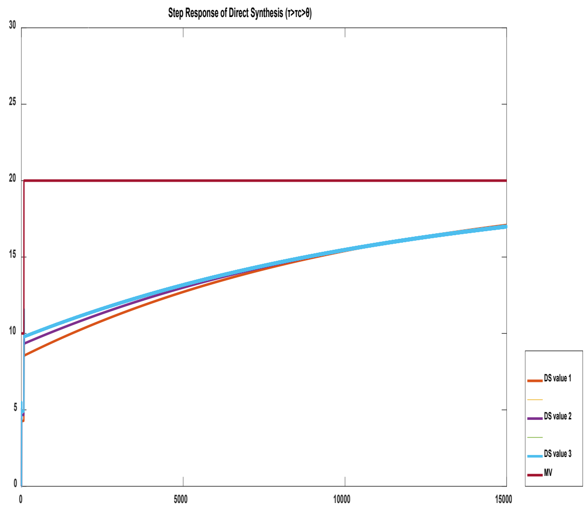

Fig. 3.7 Step Response Curve of DS

The results for the DS second tuning for different value of τ_c are shown in Figure 3.7. The first value has fast rise time and settling time compared to the other following by the second and third value. The third value has the slowest respond towards the new set point although at first it shows fast rise time. However, it is become slower with time. This is also happen to the second value which has fast rise time compared to the first value however as time goes by, the response curve move slower to the new set point.

The value of IAE for first, second and third value are 106.0, 98.91 and 94.82 respectively

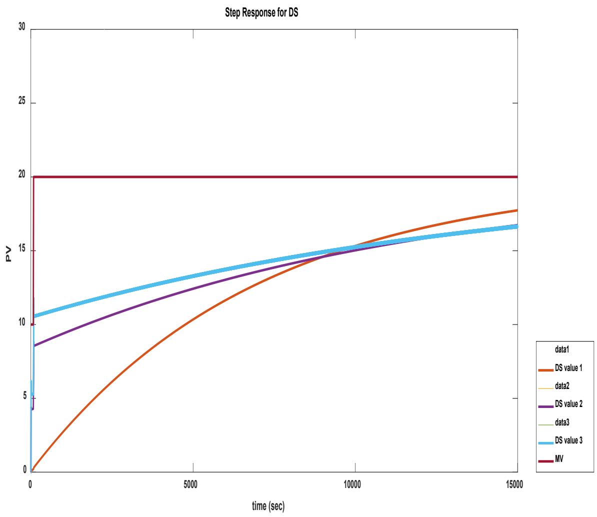

Fig. 3.8 Step Response Curve of DS

Figure 3.8 shows the comparison between the best tuning value chosen from the first and second DS tuning rule as well as the third value for the third rule. From the response curve, it was observed that the second value from the first tuning rule shows fast rise time and settling time. It has smooth increment with time and eventually settle to the new set point at the lowest time taken compared to the other. The value of IAE for first, second and third value are 178.73, 106.0 and 87.88 respectively

From all tunings, one best tuning were chose for each DS and IMC. From the comparisons made, it was found that the second tuning of DS and IMC represents as the best tuning method among the other second and third tuning. The response curve of second tuning of DS and IMC shows smooth increment of PV, fast rise time and settling time. Besides, the value of IAE for both first tuning of DS and IMC are the best which are 178.73 and 178.72 respectively compared to the other second and third tunings. Both of first DS and first IMC tunings were next being further compared as shown in Figure 3.5 to find the best tuning method between DS and IMC.

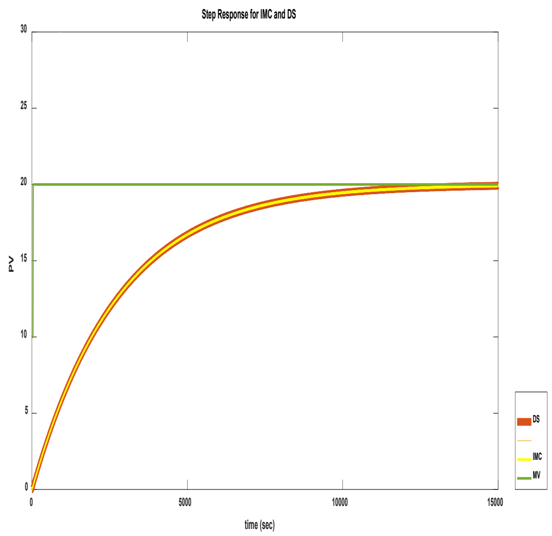

Fig. 3.5 Step Respense Curve of DS and IMC

From Figure 3.5, it was obtained that first tuning of DS and IMC produce an identical response curve. However, from the value of IAE obtained it can be conclude that DS give better performance with value of IAE 178.73.

IV. Conclusion

As a conclusion, the tuning of both methods had been successfully done by using the simulation. Comparison between both of tuning methods had been made and the best tuning method being choose. From the analysis of the results, it is determined that DS tuning method is closely related to IMC tuning method. This is due to the identical PID controllers produced by both methods [4]. Both tuning methods give fast response at low value of τ_c and high value of K_c. Thus, from this study it shows that the small value of the τ_c gives a better performance of the tuning. DS tuning method of second rule was choose to be the best method compared to IMC due to IAE, rise time and settling time despite the similarity with IMC tuning.

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