DESIGN OF CONTROLLERS FOR THREE TANK SYSTEM

A Thesis Submitted in Partial Fulfilment

Of the Requirements for the Award of the Degree of

Bachelor of Technology

in

Electronics and Instrumentation Engineering

By

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National Institute of Technology, Rourkela

Odisha-769008, India

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CERTIFICATE

This is to certify that the Thesis Report entitled "**DESIGN OF CONTROLLERS FOR THREE TANK SYSTEM**" submitted by **SAURAV KUMAR** bearing Roll no. **111EI0451** in partial fulfilment of the requirements for the award of Bachelor of Technology in Electronics and Instrumentation Engineering carried out during the academic session 2014-2015 at National Institute Of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date: -----------------------------

Prof. Umesh Chandra Pati

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Dedicated to My Parents

And Teachers

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ABSTRACT

The important part of a process industry is the analysis of chemical processes and controlling process variables by applying various control strategies. Different types of controllers are available nowadays, still conventional Proportional-Integral-Derivative (PID) controller is the most preferred one. As PID has three different tuning parameters, so it's perfect tuning is an issue till today. Many researchers have proposed different methods for tuning the controller parameters to control and fulfil needs of a process. Ziegler Nichols closed-loop method, Ziegler Nichols open-loop method, Cohen-coon method are some of the tuning methods to tune PID controller.

Further, the level control of three tank system has been analysed. In level process control, three tanks are connected in different fashions like they are purely non-interacting, purely interacting and some are combinations of interacting and non-interacting system. First, mathematical modelling of three tank system is done using basic principle of conservation of mass. The liquid level in third tank is controlled at setpoint by varying the manipulated variable which affects the first tank. Step response of each combinations of three tanks are obtained using P, PI and PID controller and process performances are compared. Internal model controller (IMC) and IMC-based PID controller are also developed for each combinations and their responses are compared with that of conventional feedback controller. The implementation of IMC and IMC-based PID controller is very difficult in case of third or higher order system. So, half rule method is used to reduce higher order transfer function into first-order plus time delay transfer function. Process performance like offset, overshoot and settling time in each cases have been analysed. Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) is used for simulation of above processes.

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LIST OF ABBREVIATIONS

LabVIEW	Laboratory Virtual Instrumentation Engineering Work Bench
PID	Proportional-Integral-Derivative
IMC	Internal Model Control
FOPDT	First Order plus Dead Time Model

CHAPTER-1

INTRODUCTION

1.1 Overview
1.2 Literature Review
1.3 Motivation
1.4 Objective
1.5 Organization of Thesis

This chapter is devoted to provide the overview of this project. It consists of brief information about different control strategies, various tuning methods for tuning PID controller. It also describes the mathematical modelling and control of different combinations of three tank level process using different methods. This is followed by literature survey, objectives and organization of the thesis.

1.1 Overview

In process industries, most of the processes and systems work with best functioning only within a narrow range of physical parameters like temperature, humidity, pressure etc. Certain chemical reactions, biological processes, and even electronic circuits perform best within limited range of parameters. So, these processes need to be optimized with well-designed controllers that keep physical parameters to within specified limits or constant. Many different control strategies like feedback, feedforward, ratio control etc. are adopted in industries. Conventional feedback controller using Proportional-Integral-Derivative (PID) algorithm is widely used due to easy tuning and perfect output.

For controlling any process, we need to do its mathematical modelling. A mathematical model of any process can be defined as "A set of mathematical equations (including the necessary input data to solve the equations) that allow us to predict the behaviour of a chemical process [2]." Models play a very important role in control system design. They are simulated to get the expected process behaviour with a proposed control system with particular set of tuning parameters.

Level process is one of the most common processes faced in industries. Owing to safety or process requirement, the level of the process liquid must be maintained at a certain level in spite of the disturbances. Level process may consist of single tank which is very simple to analyse and control, or it may consist of two or more tanks which are very complex and difficult to control. It may be controlled by different control strategies like PID, Internal Model Control (IMC), etc. Almost 90% of the controllers used in industries are conventional PID controller. Many researchers have proposed different tuning method like Ziegler Nichols method, Cohen Coon method, Process Reaction method etc. to tune PID controllers.

Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) is generally used for interfacing with hardware such as data acquisition, industrial automation and instrument control. The simulations and response generation of all the systems discussed in this work has been done using LabVIEW.

1.2 Literature Review

The literature study of this project begins with study of the basics of process control. In [1], different control strategies used in process industries have been studied followed by detailed study of feedback controllers. This was followed by learning about P, PI and PID controllers and their mathematical equations [2].

N. Khera, S. Balguvhar and B.B. Shabarinath [3] had explained basics of PID controller and used Ziegler Nichols tuning method for tuning second order process. He analysed response of P, PI and PID controller using step input.

J. C. Basilio and S. R. Matos [4] had explained Ziegler Nichols closed-loop & open-loop method and Cohen-Coon method and had implemented these methods on different process and their responses were analysed. He explained response of second order process and first-order plus time delay function. First order time delay function was tuned using Cohen Coon method and Ziegler Nichols open loop method.

J.S Lather and L. Priyadarshini [5] had explained Internal model control (IMC) and IMC-based PID controller for higher order process. He had used half rule method to reduce higher order transfer function to first order plus time delay function. He also explained different tuning methods to tune PID controller.

M.Suresh and G.J Srinivasan [6] had explained the mathematical modelling of three tank interacting, non-interacting and their various combinations. The transfer function of each process is obtained and tuned using Ziegler Nichols tuning method.Different tuning methods are also explained here.

E. Kumar and M. Sankar [7] had explained the mathematical modelling of three tank interacting, non-interacting and their various combinations and analysed the oscillation of response and studied the effect of valve stiction.

1.3 Motivation

As feedback controller is simple and easy, so it is mostly used in process industries to control processes. Most of the feedback controller consists of PID controller whose tuning is a big issue for an engineer working in the process industries. Many researchers have proposed different tuning methods to optimize any process. As the type of transfer function varies from process-to-process, so different tuning methods are suitable for different types of processes. Optimum tuning of parameters results in optimum performance of processes by controllers.

The control of level in a tank is a common task in any industry .These tuning methods are applied on three tank level process. Simulation results help us to understand and control the process.

1.4 Objectives

The objectives of this thesis are:

- Applying different tuning methods to tune a process.
- Mathematical modelling of different combinations of three tank system.
- Reducing higher order process transfer function to FOPDT function.
- Controlling the level of liquid in third tank using different control strategies.

1.5 Organisation of thesis

It consists of four chapters. First is the introduction of the project work. The other three chapters are:

CHAPTER 2- DIFFERENT TYPES OF PID TUNING METHODS

It includes different types of PID tuning method to optimize different types of process. All tuning methods do not work/optimize all processes, so different tuning methods are used to tune different types of process transfer function.

CHAPTER 3- CONTROL OF THREE TANK LEVEL PROCESS

This chapter describes the mathematical modelling of non-interacting, interacting and different combinations of three tank level process. The combinations are controlled using conventional P, PI and PID controller where overshoot and settling time is measured. Further, IMC and IMC-PID are implemented on above process transfer function to minimize overshoot.

CHAPTER 4- CONCLUSIONS

This chapter concludes the progress of work done in this project. It also highlights the future scope of this work.

CHAPTER-2

PID TUNING METHODS

This chapter includes the basics of feedback control system [1]. It describes about P, PI and PID controller and their different tuning methods [2]. These tuning methods are implemented on different types of process transfer function and simulations are analysed.

2.1 Basic of P, PI and PID controller

In process industries, different control strategies are used nowadays as per their requirements and convenient. Feedback control strategy is the most commonly used control method used in industries. It is the control mechanism that uses information from measurements of controlled variable to manipulate a variable to achieve the desired result. The feedback controller is 'driven' by the error between the actual process output and the setpoint [1]. Feedback controllers are classified into different categories.

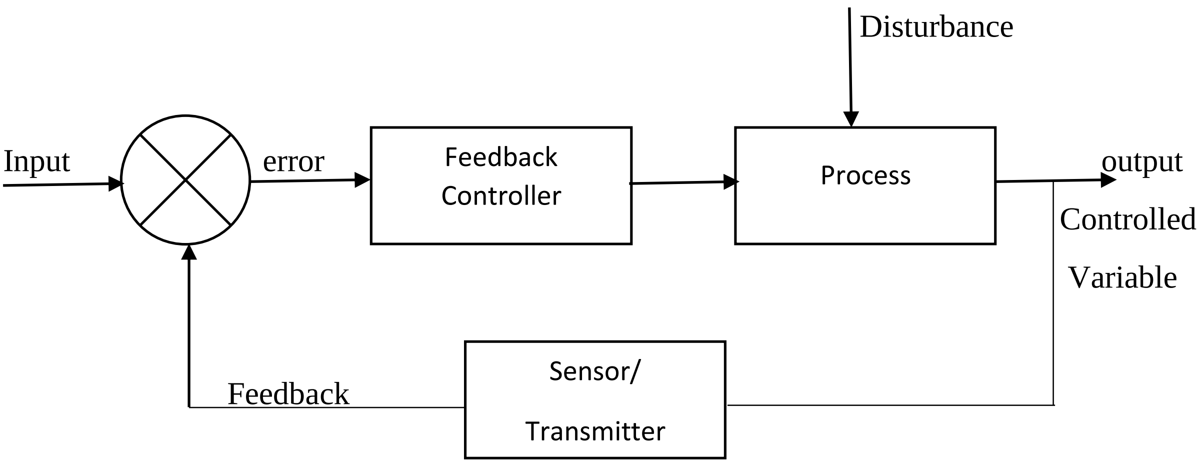

Fig 1: Block diagram of feedback control system

- *Proportional Controller* (P) - The proportional gain can be mathematically expressed as the ratio of the output response to the error signal. Generally, as we increase the value of proportional constant, the speed of the control system response also increases. When the gain of controller is increased above a certain value, then the process response starts to oscillate. If the gain is increased further, the system tends towards instability. In P controller only proportional constant need to be observed, the other two values integral constant and derivative constant is set to zero[2].
- *Proportional-Integral Controller* (PI) - PI controller is combination of proportional and integral terms which is important in increasing the speed of response and also eliminate the steady state error. It adds the error and increases the integral constant till error becomes zero. So, steady state error is zero in case of PI controller. That also increases

the time constant of system and pushes the system towards instability. Its step response is oscillating in nature, so it's settling time is large [2].

- *Proportional-Integral-Derivative Controller* (PID) - PID controller is an appropriate combination of proportional, integral and derivative terms to provide all the desired performances of a closed loop system. It also gives zero steady state error and overshoot is also very less. PID controller are recommended for use in slow processes and which are free from noise. The PID controller can be realized as a controller that takes account of the present, the past and the future of the error [2, 3]. Mathematically, PID controller is expressed as

$$G_c(s) = K_c\left(1+\frac{1}{\tau_{i\,s}}+\tau_d s\right) \tag{1}$$

The adjustment of control parameters to the favourable condition for the desired control response is called tuning of a process. The tuning of PID controller refers to the determination of proportional gain (K_c), integral time (τ_i) and derivative time (τ_d). As PID controller has three parameters to be adjusted, so many different methods have been developed. Many researchers have proposed different tuning methods for tuning PID controller. Some of the main tuning methods are described below.

2.2 Ziegler- Nichols Method

In 1942, Ziegler and Nichols explained simple mathematical procedures for tuning PID controllers. These procedures are now accepted as standard in control systems practice [4]. They proposed a mathematical table for tuning each parameters of PID controller. They proposed different procedures for open loop and closed loop systems.

2.2.1 *Ziegler-Nichols Open-Loop Method*

In this method we have to obtain step response of open loop system, so it is also called *process curve method*.

Steps involved in tuning a process using this method [1] are

a) Make an open-loop step test of process transfer function.

b) From the process reaction curve, determine dead time (τ_{dead}), time constant (τ), ultimate value that the response reaches at steady state, M_u for a step change of X_0.

$$K_0 = \frac{X0}{Mu} * \frac{\tau}{\tau dead} \tag{2}$$

c) Obtain PID tuning parameters using Table 1.

Table 1: Ziegler-Nichols Open-Loop Tuning Parameters [1]

	K_c	T_i	T_d
P	K_0	∞	0
PI	$0.9K_0$	$3.3\ \tau_{dead}$	0
PID	$1.2\ K_0$	$2\ \tau_{dead}$	$0.5\ \tau_{dead}$

Mathematical analysis:

Process Transfer Function: G(s) = $\frac{1}{s^2+s+0.25}$

Step input response of open loop transfer function is obtained as shown in Fig. 2. From process curve, dead time (τ_{dead}), time constant (τ), ultimate value that the response reaches at steady state, M_u for a step change of X_0 and K_0 are obtained. we get

X_0 =1 unit

M_u =3.75 unit

τ_{dead} =1.2 sec

$\tau = 7 - 1.2 = 5.8\ sec$

So, K_0=1.288

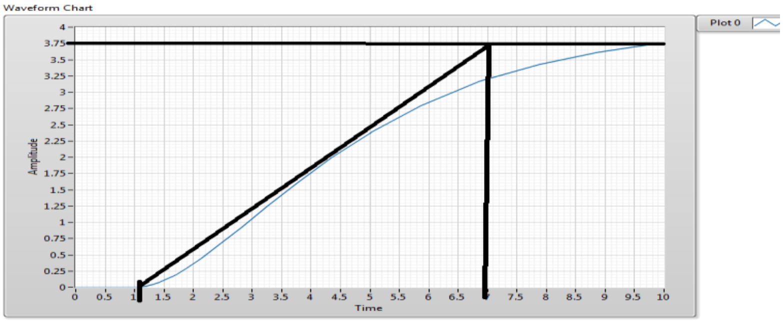

Fig. 2: Open loop response of process transfer function

On substituting above values obtained from open loop curve into Table 1, we get tuning parameters as shown in Table 2.

Table 2: calculated tuning parameters for Ziegler-Nichols Open Loop Method

	K_c	**T_i(sec)**	**T_d(sec)**
P	1.288	∞	0
PI	1.16	3.96	0
PID	1.54	2.4	0.6

Since open loop response is uncontrollable, so it is required to control the output via different control strategies. Step input response has been obtained for the process using different feedback controllers like P, PI and PID.

Results:

Above tuning parameters are put to get the simulation shown in Fig. 3.

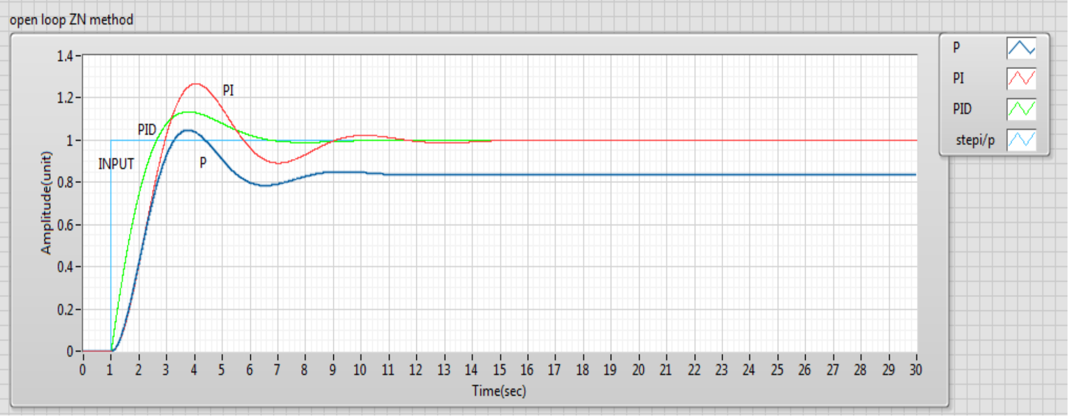

Fig. 3: Step response of process transfer function using Ziegler-Nichols open-loop method

The above response shows that P, PI and PID controllers have different characteristics. Rise time (T_r), Settling time (T_s), maximum overshoot and offset error are obtained from the simulation and are compared. The comparison is shown in Table 3.

Table 3: Comparison of process performance in P, PI and PID controller

	Rise time(sec)	Settling time(sec)	%maximum Overshoot	%Offset error
P	3.6	11	2	20
PI	4.0	15	30	0
PID	3.2	6.5	9	0

Table 3 shows that P controller has lowest overshoot, but has offset error. PI controller has zero offset error but has large overshoot and its settling time is also larger than P controller. PID controller has least rise time, least settling time, zero offset and lower overshoot. So, PID controller is best suited in industries and almost 90% of controller used in industries are PID controller.

2.2.2 Ziegler-Nichols Closed-Loop Method

This method is very old one and is based on closed-loop control system [2, 5]. The steps involved in tuning PID controllers are:

a) The characteristic equation of closed-loop system is obtained.
b) $s=i\omega$ is put to the equation, and the value of ultimate gain, K_{cu} and ultimate time, $T_{u.}$ is obtained.
c) Above values are substituted to Table 4 to get different tuning parameters of PID controller.

Table 4: Ziegler-Nichols closed-loop method Tuning Parameters [2]:

	K_c	T_i(sec)	T_d(sec)
P	0.5 K_{cu}	∞	0
PI	0.45 K_{cu}	$T_u/12$	0
PID	0.5 K_{cu}	$T_u/2$	$T_u/8$

Mathematical analysis:

Process transfer function, $G(s) = \frac{1}{s^3+3s^2+3s+1}$

Controller transfer function, $G_c(s) = K_c$

So, characteristic equation is

$1+G(s)*G_c(s) = 0$

Or, $s^3+s^2+3s+1+K_c=0$

By direct substitution method,

i.e, putting $s=i\omega$, we get

Ultimate gain, $K_{cu}=8$, and

Ultimate time, $T_u=3.627$sec

On substituting above values to Table 4, PID tuning parameters are calculated and shown in Table 5.

Table 5: Calculated Ziegler-Nichols closed-loop method Tuning Parameters:

	K_c	T_i(sec)	T_d(sec)
P	4	∞	0
PI	3.6	3.016	0
PID	4.8	1.81	0.45

Results

Tuning parameters shown in Table 5 are put to simulation of the given process transfer function. The step response of P, PI and PID controllers are obtained using simulation and are shown in Fig. 4.

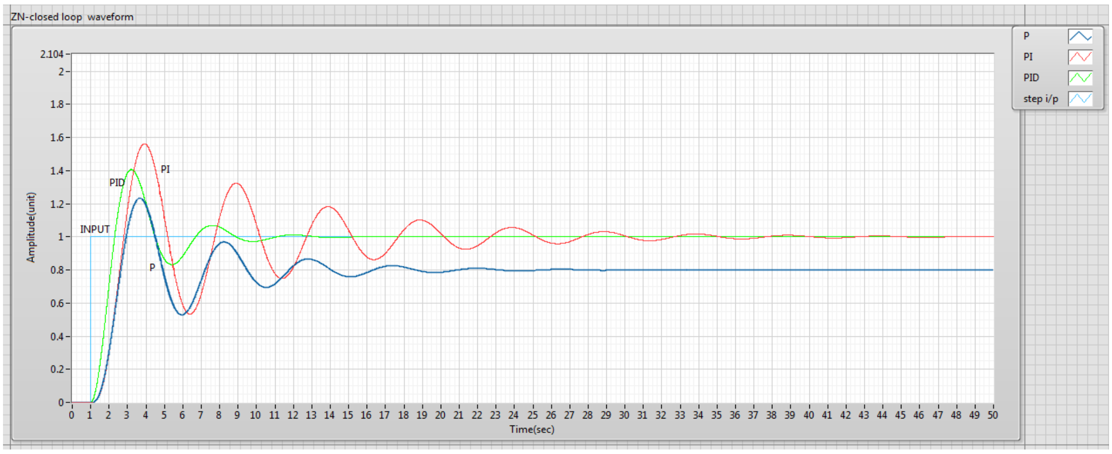

Fig. 4: Step response of process transfer function using Ziegler-Nichols closed-loop method

The above response shows that P, PI and PID controllers have different step response. Rise time (T_r), Settling time (T_s), maximum overshoot and offset error are obtained from the simulation and are compared. The comparison is shown in Table 6.

Table 6: Comparison of process performance in P, PI and PID controller

	Rise time(sec)	Settling time(sec)	%maximum Overshoot	%offset error
P	3.6	22	20	20
PI	4.1	13	56	0
PID	2.9	38	40	0

Table 6 shows that P controller has lowest overshoot, but has offset error. PI controller has zero offset error but has large overshoot and its settling time is also larger than P controller. PID controller has least rise time, least settling time, zero offset and lower overshoot. So, PID controller is best suited in industries and almost 90% of controller used in industries are PID controller.

2.3 Cohen-Coon Method

Cohen-Coon method was developed by Cohen and Coon in 1953, which is based on first-order plus time-delay process model [1]. This was similar to Ziegler Nichols tuning method. The tuning parameters as a function of model parameters are shown in Table 6.

Consider a first-order plus time-delay process transfer function

$$G(s) = \frac{K_p}{\Gamma s+1} \; e^{-\theta s} \qquad (3)$$

Table 7: Cohen-Coon Tuning Parameters

	K_c	T_i(sec)	T_d(sec)
P	$\frac{\Gamma}{k_p\theta}[1+\frac{\theta}{3\Gamma}]$	∞	0
PI	$\frac{\Gamma}{k_p\theta}[0.9+\frac{\theta}{12\Gamma}]$	$\theta[\frac{30+3\theta/\Gamma}{9+20\theta/\Gamma}]$	0
PID	$\frac{\Gamma}{k_p\theta}[\frac{4}{3}+\frac{\theta}{4\Gamma}]$	$\theta[\frac{32+6\theta/\Gamma}{13+8\theta/\Gamma}]$	$\frac{4\theta}{11+2\theta/\Gamma}$

Mathematical analysis:

Process Transfer function is

$G(s) = 2e^{-3s}/(5s+1)$

So, $K_p = 2$, $\Gamma = 5$, $\theta = 3$

Substituting above process parameters to Table 7, we get PID tuning parameters values, shown in Table 8.

Table 8: Calculated Cohen-Coon Tuning Parameters:

	K_c	T_i(sec)	T_d(sec)
P	1	∞	0
PI	0.796	4.54	0
PID	1.233	6	0.984

Results:

Tuning parameters shown in Table 8 are put to simulation of the given process transfer function. The step response of P and PI controllers are obtained using simulation and are shown in Fig. 5.

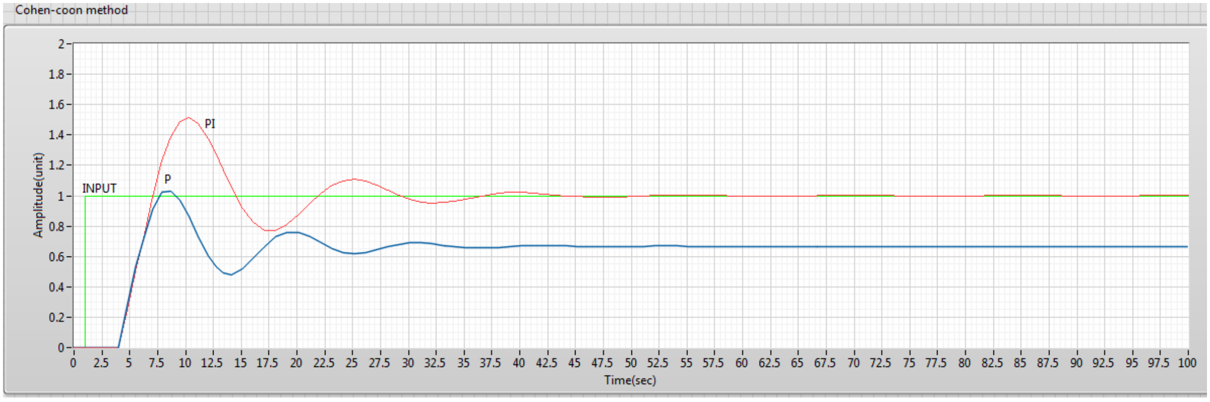

Fig. 5: Step response of P and PI controllers using Cohen-Coon Method

The step response shown in Fig. 5 shows that P and PI controller have different process performances. PID controller does not give smooth settling curve, so PID controller is not tuned using this method. PID controller needs additional filter to tune the process. Table 9 shows the comparison of process performances in P and PI controller.

Table 9: Comparison of process performance in P and PI controller

	Rise time(sec)	Settling time(sec)	%maximum Overshoot	Offset error
P	7.6	32.5	1	0.3
PI	10	45	50	0

Table 9 shows that maximum overshoot in case of PI controller is very high, and offset error is zero. So, it can be used processes where overshoot is not of much concern.

CHAPTER-3

CONTROL OF THREE TANK LEVEL PROCESS

3.1 Basics of IMC and IMC-PID controller

3.2 Three Tank Non-Interacting System

3.3 Three Tank Interacting System and Combination of Non-Interacting and Interacting System

This chapter includes mathematical modelling of non-interacting, interacting three tank process and various combinations of non-interacting and interacting system. The mathematical modelling is based on the basic principle of conservation of mass in each tank. This principle states that that the rate of accumulation in the tank is equal to the difference between inlet mass flow rate and outlet mass flow rate. First, conventional PID controller is implemented to control the level of process in tank 3 by varying manipulated variable in tank 1. It gives overshoot and settle slowly. Further, Internal Model Controller (IMC) is implemented for controlling purpose. IMC is based upon the internal model principle to combine the process model and external signal dynamics [5].It is able to handle time delays and helps in obtaining uniformity, disturbance rejection, and set point tracking, all of which leads to better process economics [6]. It has a combined advantage of both open and closed system. Since implementation of IMC controller directly to higher order system is very difficult due to increased complexity. So, it is reduced to lower order system using half-rule method [6]. According to half-rule method, the largest neglected (denominator) time constant (lag) is distributed evenly to the effective delay and the smallest time constant retained [5].

Here, Ziegler-Nichols tuning method has been used to tune the process. Step response of P, PI and PID controller is obtained using LabVIEW. IMC and IMC-PID have been implemented to overcome the problems faced in PID controller.

3.1 IMC and IMC-based PID controller

The model-based controller design algorithm named "Internal Model Control" (IMC) has been presented by Garcia and Morari [1], which is based upon the internal model principle to combine the process model and external signal dynamics. The IMC-PID controller tuning strategy not only has the advantage of internal model control, but also includes the characteristic of conventional PID controller, but also has the advantages of internal model control. IMC-PID tuning method is a clear trade-off between closed-loop performance and robustness to model inaccuracies which is achieved with a single tuning parameter i.e. filter coefficient. The step response of IMC and IMC-based PID controller is different because later uses the approximation of time delayed function while former does not uses approximation. Block diagram of IMC and IMC-based PID structure are shown in Fig. 6 and Fig.7 [1].

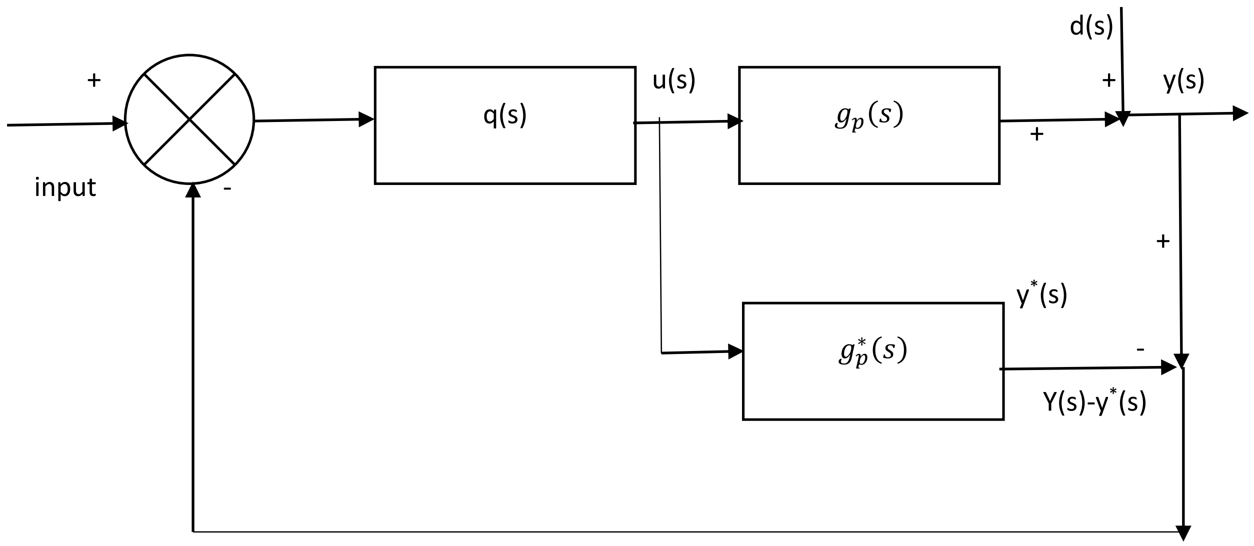

Fig.6: Block diagram of IMC controller

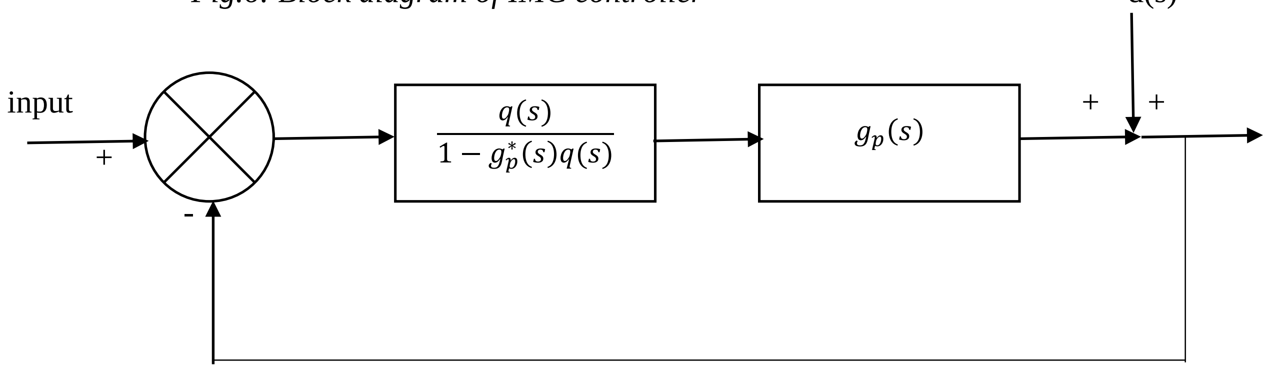

Fig.7: Block diagram of IMC based PID controller.

Advantages of IMC controller:-

- It provides time delay compensation.
- Filter can be used to shape both the setpoint tracking and disturbance rejection.
- At steady state, IMC controller gives offset free response.

Advantages of IMC-based PID controller:-

- IMC-based PID controller can be used for unstable systems also.
- It does not require that the controller be proper.
- Time delays are approximated by Pade's approximation.

It is difficult to design filter coefficient of controller in IMC and IMC-based PID controller for third or higher order system. So, *Half-Rule Method* is used to reduce higher order transfer function to first order plus time delay function [5].

3.2 Three Tank Non-Interacting System

Tanks are not connected to each other, so it is called non-interacting system. In this type of system, one tank does not affect the functioning of other tank. The process shown in Fig. 6 is a three tank non-interacting process in which the inlet flow rate of liquid is pumped to tank 1.The outlet flow rate of tank 1 is non-interacting with tank 2 and tank 2 is also connected with tank 3 in the same fashion.

Mathematical Modelling

Tank 1

Mass balance equation for the contents of the tank1 is

Rate of mass into tank 1- Rate of mass out of tank 1=Rate of accumulation in tank 1 [7]

$$\rho F_1(t) - \rho F_2(t) = \rho A_1 dh_1 / dt \tag{4}$$

$$F_2(t) = h_1(t) / R_1 \tag{5}$$

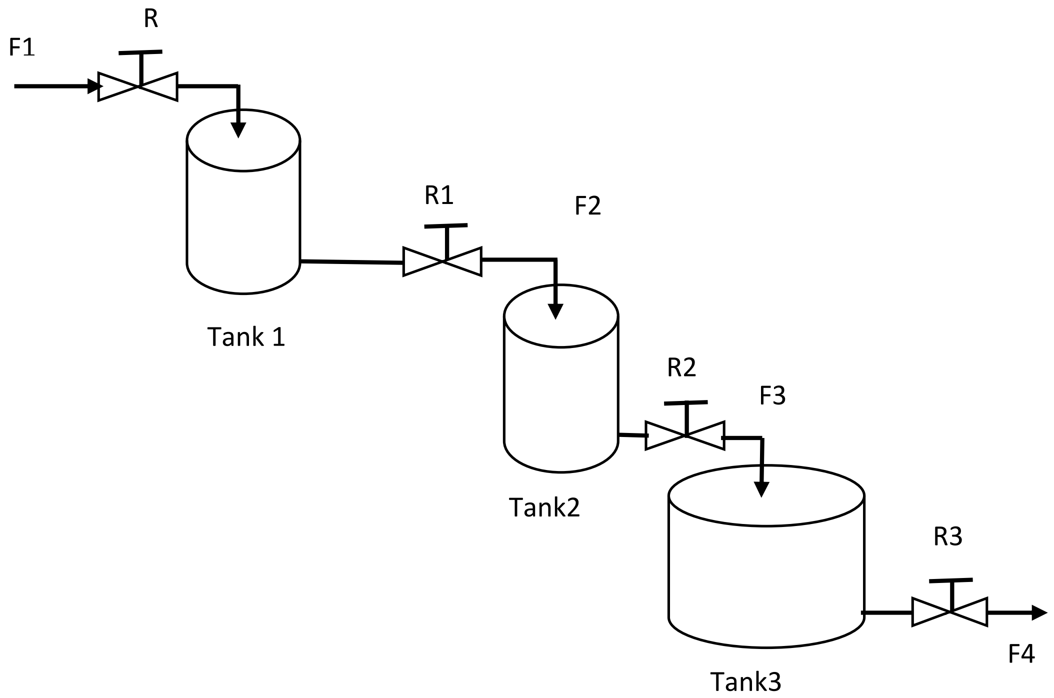

Fig. 8: Three tank non-interacting Process

Where,

F_1 – Tank 1 inlet flow rate (m^3/s)

F_2 – Tank 1 outlet flow rate (m^3/s)

R_1 - Outlet flow rate of resistance of tank1 (m/ (m^3/s))

A_1 - Cross-section area of tank 1 (m^2)

h_1 - liquid level in tank 1 (m)

ρ - density of liquid (Kg/m^3)

Tank2

Mass balance equation for the contents of the tank2 is

$$\rho F_2(t) – \rho F_3 (t) = \rho A_2 dh_2 / dt \tag{6}$$

$$F_3 (t) = h_2 (t) / R_2 \tag{7}$$

Where,

F_2 – Tank 2 inlet flow rate (m^3/s)

F_3 – Tank 2 outlet flow rate (m^3/s)

R_2 - outlet flow rate of resistance of tank 2 (m/ (m^3/s))

A_2 - cross-section area of tank 2 (m^2)

h_2 - liquid level in tank 2 (m)

ρ - density of liquid (Kg/m^3)

Tank3

Mass balance equation for the contents of the tank3 is

$$\rho F_3(t) – \rho F_4 (t) = \rho A_3 dh_3 / dt \tag{8}$$

$$F_3 (t) = h_3 (t) / R_3 \tag{9}$$

Where,

F_3 – Tank 3 inlet flow rate (m^3/s)

F_4 – Tank 3 outlet flow rate (m^3/s)

R_3 - outlet flow rate of resistance of tank 3 (m/ (m^3/s))

A_3 - cross-section area of tank 3 (m^2)

h_3 - liquid level in tank 3 (m)

ρ - density of liquid (Kg/m^3)

The overall transfer function of three tank non-interacting process is determined using Eq. (1) to Eq. (6) and obtained equation is

$$\frac{H_3(s)}{F_1(s)} = \frac{R_3}{(A_1R_1s+1)(A_2R_2s+1)(A_3R_3s+1)} \quad (10)$$

By considering $A_1 = A_2 = 1\ m^2$, $A_3 = 0.5\ m^2$

$R_1 = R_2 = 2\ (m/(m^3/s))$, $R_3 = 4\ (m/(m^3/s))$ [2];

$$\frac{H_3(s)}{F_1(s)} = \frac{4}{8s^3+12s^2+6s+1} \quad (11)$$

Using half-rule method [3], third order equation is reduced to first order with time delay function. The above equation is reduced to

$$\frac{H_3(s)}{F_1(s)} = \frac{4}{3s+1}e^{-3s} \quad (12)$$

Simulations

The three tank non-interacting process is designed and simulated using LabVIEW. The simulation of process with the conventional PID, IMC and IMC-based PID scheme have been shown in Fig. 10, Fig. 11 and Fig. 12 respectively.

3.3 Three Tank Interacting System and Combination of Non-Interacting and Interacting System

Three tank system can have different combinations of interaction and no-interaction among each other. Mainly, three combinations are discussed here.

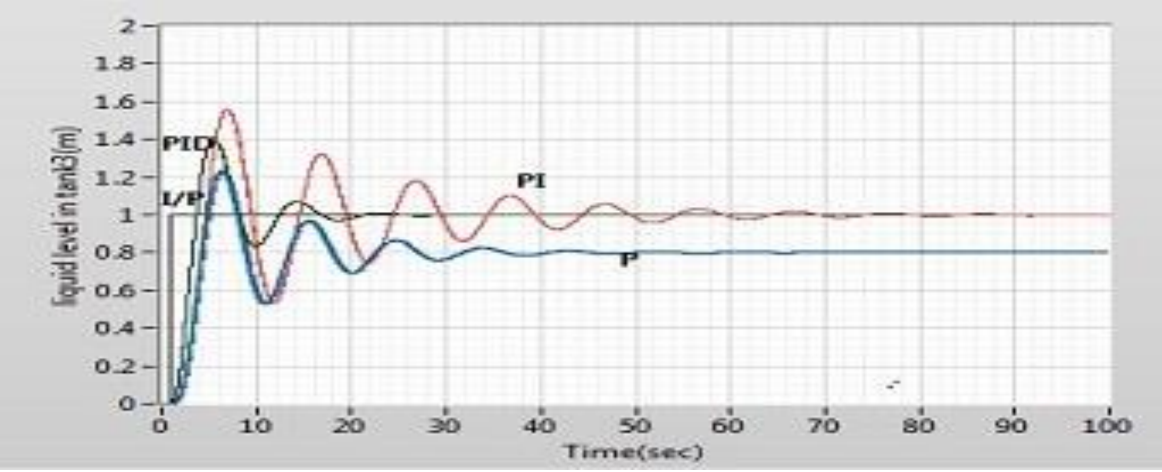

Fig. 9: Step response of P, PI, and PID controller of three tank non-interacting process

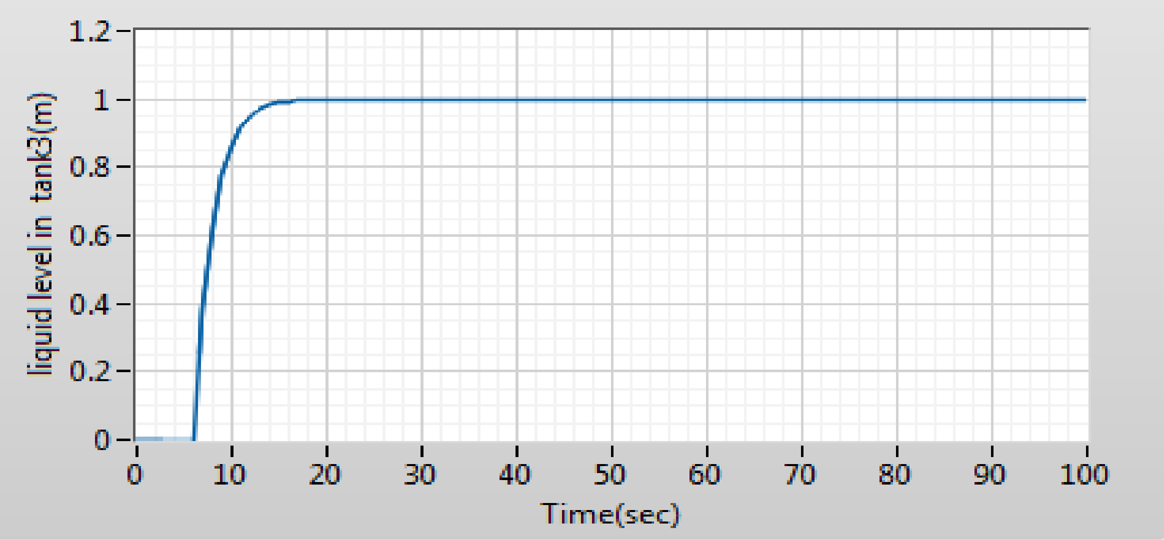

Fig. 10: Step response using IMC control scheme of three tank non-interacting process

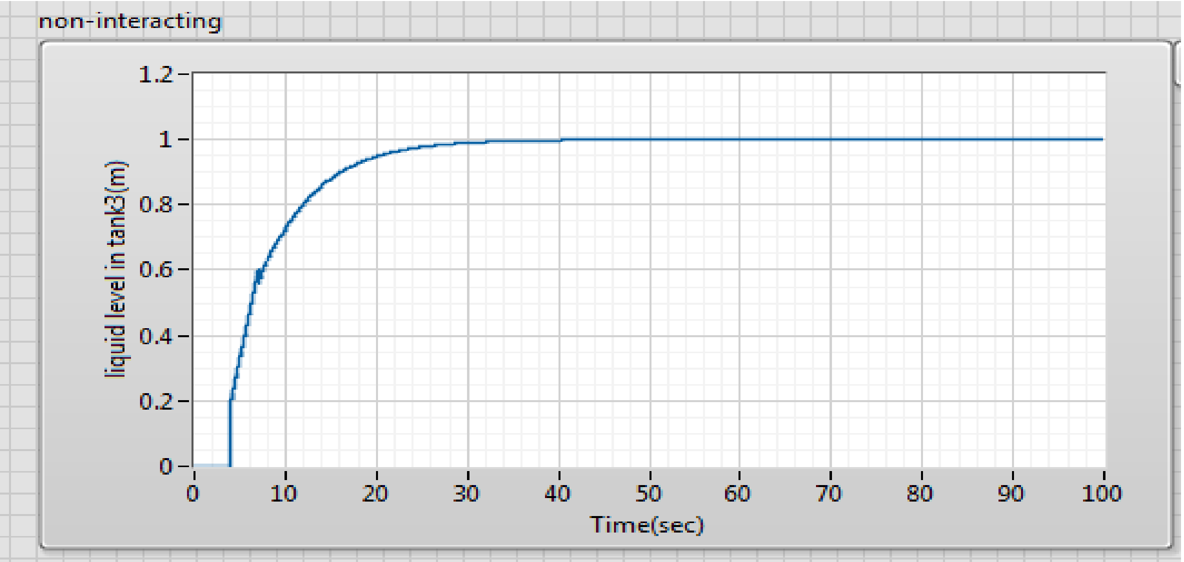

Fig. 11: Step response using IMC-based PID control scheme of three tank non-interacting process

3.2.1 Interacting Three Tank system: CASE I

The three tank interacting system is shown in Fig. 12. The interaction occurs due to the connection between two tanks [4] and the figure shows that tank 1, tank 2 and tank 3 are connected to each other.The outlet flow of tank 1 is interacting with tank 2 and the outlet flow of tank 2 is interacting with tank 3.

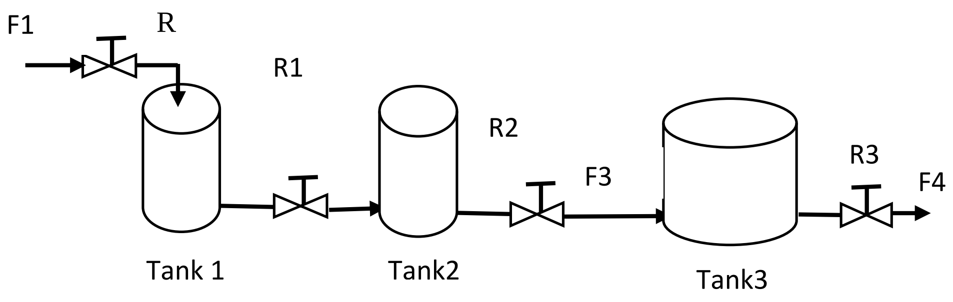

Fig. 12: Three tank interacting Process: CASE I

Mathematical Modelling

The outlet flow equation of tank 1, tank 2 and tank 3 respectively are [7]:

$F_2(t) = [h_1(t)-h_2(t)] / R_1,$ (13)

$F_3(t) = [h_2(t)-h_3(t)] / R_2,$ (14)

$F_4(t) = h_3(t) / R_3;$ (15)

On substituting Eq. (13), (14) and (15) into Eq. (4), (6) and (8), the overall transfer function of three tank interacting system is obtained, which is

$$\frac{H_3(s)}{F_1(s)} = \frac{R_1R_2R_3}{[(A_1R_1s+1)(A_2R_2R_1s+R_1+R_2)-R_2)](A_3R_3R_2s+R_2+R_3)-R_1R_3\,(A_1R_1s+1)} \quad (16)$$

By considering $A_1 = A_2 = 1\ m^2$, $A_3 = 0.5\ m^2$

$R_1 = R_2 = 2\ (m/(m^3/s))$,$R_3 = 4\ (m/(m^3/s))$ [3] ;

$$\frac{H_3(s)}{F_1(s)} = \frac{4}{8s^3+24s^2+16s+1} \quad (17)$$

Using half rule method [6], it is reduced to

$$\frac{H_3(s)}{F_1(s)} = \frac{0.5}{14.85s+1}\,e^{-1.05s} \quad (18)$$

Simulations

The three tank interacting process is designed and simulated using LabVIEW. The simulation using the conventional PID, IMC and IMC-based PID control schemes have been shown in Fig. 13, Fig. 14and Fig. 15 respectively

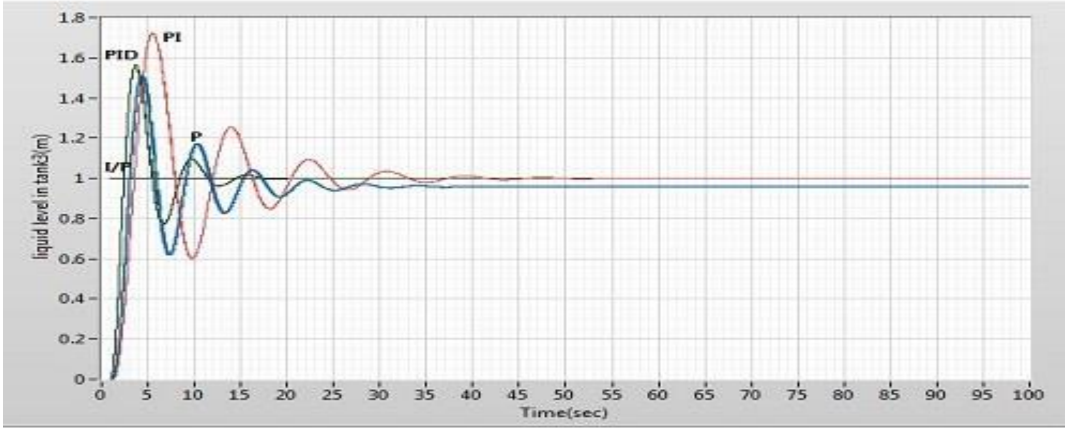

Fig. 13: Step response of three tank interacting process (CASE: I) using P, PI and PID controller

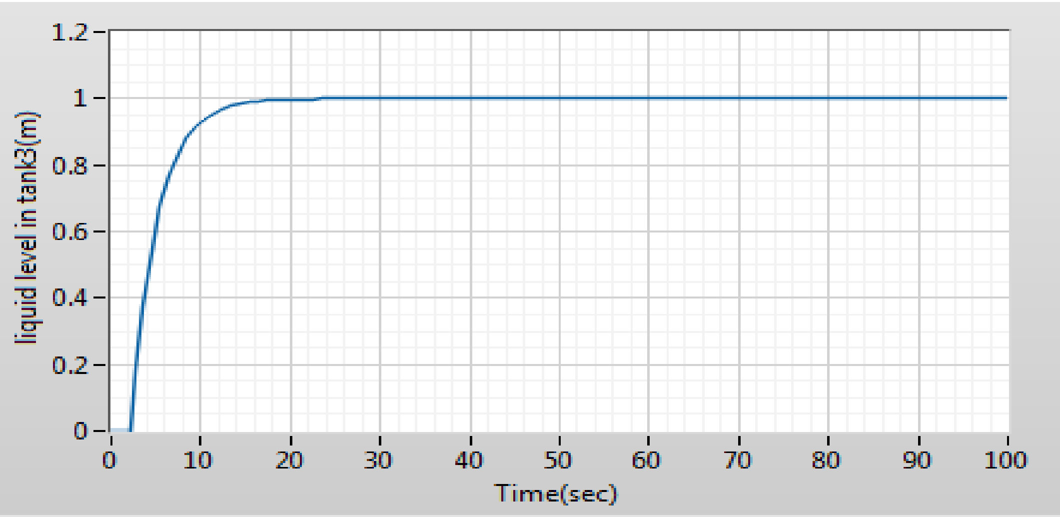

Fig. 14: Step response of three tank interacting process (CASE: I) using IMC controller

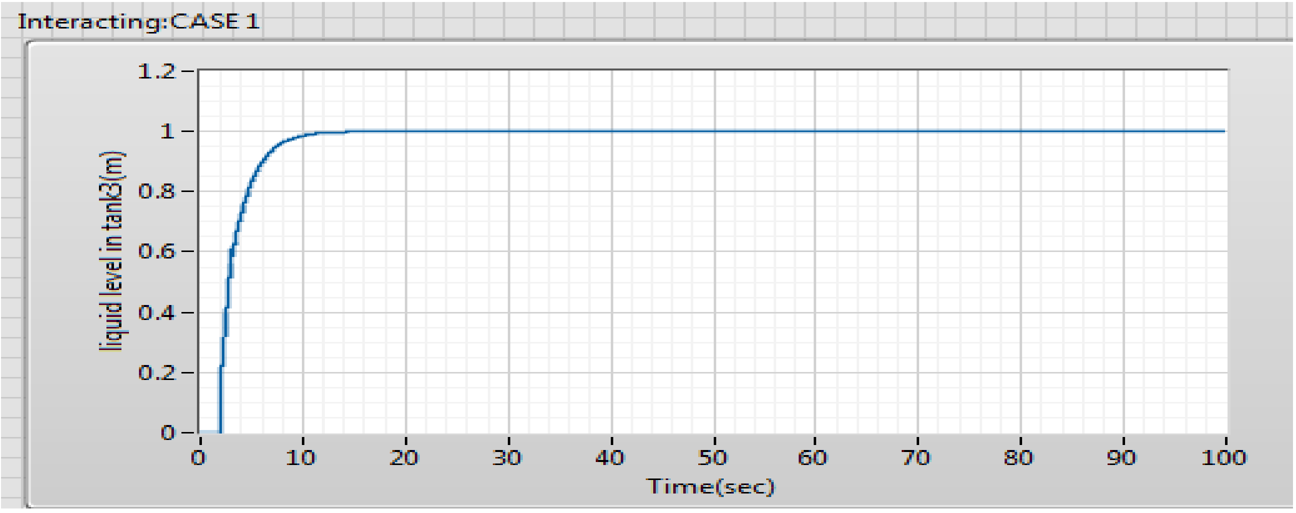

Fig. 15: Step response of three tank interacting process (CASE: I) using IMC-based PID controller

3.2.2 Three tank interacting process: CASE II

Combination of interacting and non-interacting three tank system is shown in Fig. 16.It shows that tank 1 is interacting with tank 2 and tank 3 is non-interacting with tank 2.

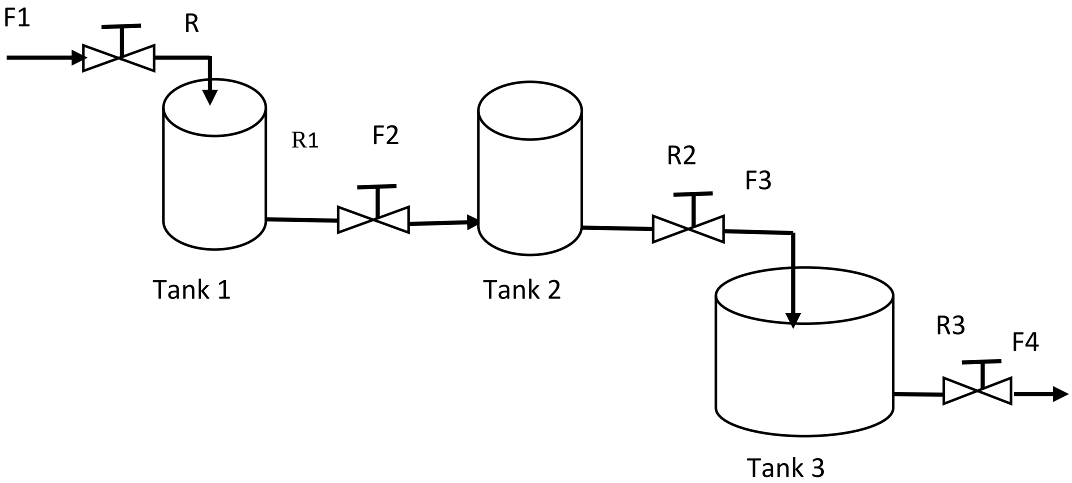

Fig.16: Three tank interacting Process: CASE II

Mathematical Modelling

The outlet flow equation of tank 1, tank 2 and tank 3 respectively are [7]:

$$F_2(t) = [h_1(t)-h_2(t)] / R_1, \tag{19}$$

$$F_3(t) = h_2(t)/ R_2, \tag{20}$$

$$F_4(t) = h_3(t) / R_3; \tag{21}$$

On substituting Eq. (19), (20) and (21) into Eq. (4), (6) and (8), the overall transfer function of three tank interacting process is obtained, which is:

$$\frac{H_3(s)}{F_1(s)} = \frac{R_1R_3}{\begin{array}{c}[(A_1R_1s+1)(A_2R_2R_1s+R_1+R_2)-R_2)]\\(A_3R_3s+1)\end{array}} \tag{22}$$

By considering $A_1 = A_2 = 1\ m^2$, $A_3 = 0.5\ m^2$

$R_1 = R_2 = 2\ (m/(m^3/s))$,$R_3 = 4\ (m/(m^3/s))$ [3] ;

$$\frac{H_3(s)}{F_1(s)} = \frac{4}{8s^3+16s^2+8s+1} \tag{23}$$

Using half rule method [3], it is reduced to

$$\frac{H_3(s)}{F_1(s)} = \frac{0.52}{6s+1}e^{-1.77s} \tag{24}$$

Simulations

The combination of three tank interacting and non-interacting process is designed and simulated using LabVIEW. The simulation using the conventional PID and IMC scheme have been shown in Fig. 17, Fig. 18 and Fig. 19 respectively.

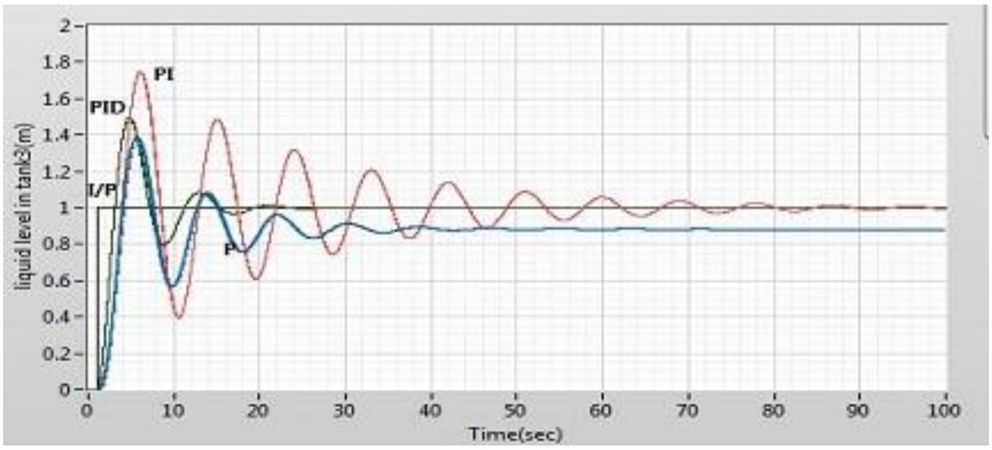

Fig. 17: Step response of three tank interacting process (CASE: II) using conventional P, PI and PID controller

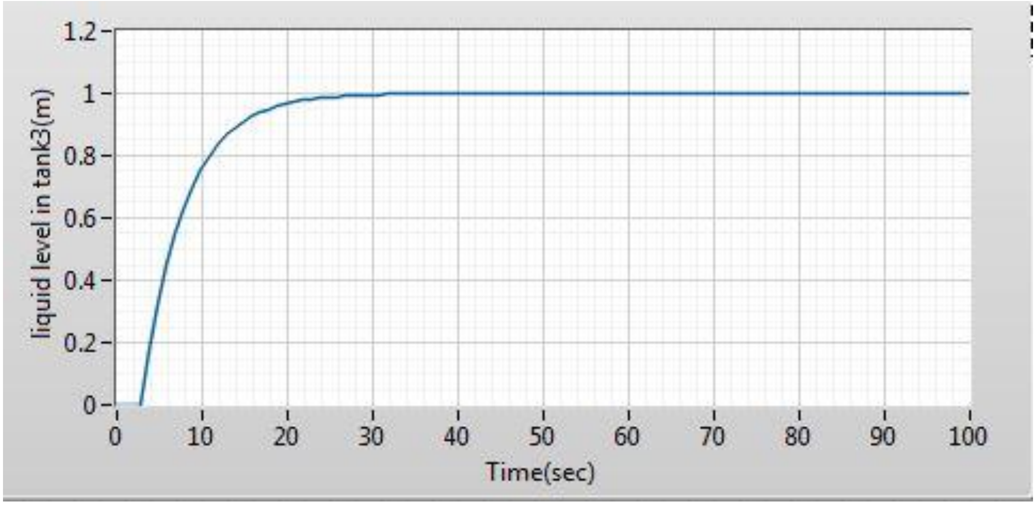

Fig. 18: Step response of three tank interacting process (CASE: II) using IMC controller.

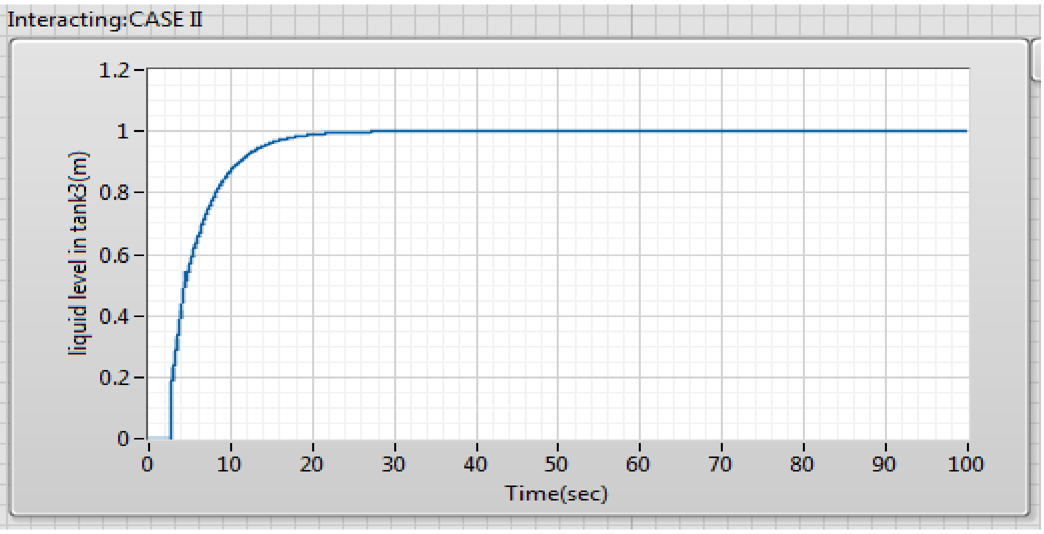

Fig. 19: Step response of three tank interacting process (CASE: II) using IMC-based PID controller.

3.2.3 Three Tank Interacting Process: CASE III

Fig. 20 shows combination of interacting and non-interacting three tank system in which tank 1 is non-interacting with tank 2 and tank 3 is interacting with tank 2.

Mathematical Modelling

The outlet flow equation of tank1, tank2 and tank3 respectively are [7]:

$$F_2(t) = h_1(t)/ R_1, \tag{25}$$

$$F_3(t) = [h_2(t)-h_3(t)] / R_2, \tag{26}$$

$$F_4(t) = h_3(t) / R_3; \tag{27}$$

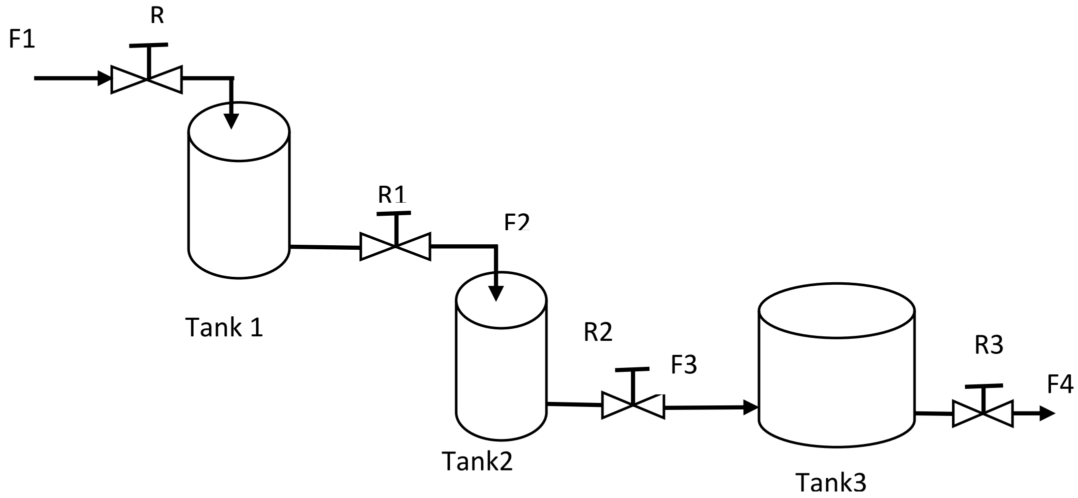

Fig.20: Three tank interacting Process: CASE III

On substituting Eq. (22), (23) and (24) into Eq. (1), (3) and (5), the overall transfer function of three tank interacting system is obtained, which is:

$$\frac{H_3(s)}{F_1(s)} = \frac{R_2R_3}{\frac{((A_2R_2s+1)(A_3R_2R_3s+R_2+R_3)-R_3)}{(A_1R_1s+1)}} \tag{28}$$

By considering $A_1 = A_2 = 1\ m^2$, $A_3 = 0.5\ m^2$

$R_1 = R_2 = 2\ (m/(m^3/s))$,$R_3 = 4\ (m/(m^3/s))$ [6] ;

$$\frac{H_3(s)}{F_1(s)} = \frac{4}{8s^3+20s^2+10s+1} \tag{29}$$

Using half rule method it is reduced to

$$\frac{H_3(s)}{F_1(s)} = \frac{0.5}{8.5s+1}e^{-1..53s} \tag{30}$$

Simulations

The combination of three tank interacting and non-interacting process is designed and simulated using LabVIEW. The simulation using the conventional PID, IMC and IMC-based PID scheme have been shown in Fig. 21, Fig.22 and Fig. 23 respectively.

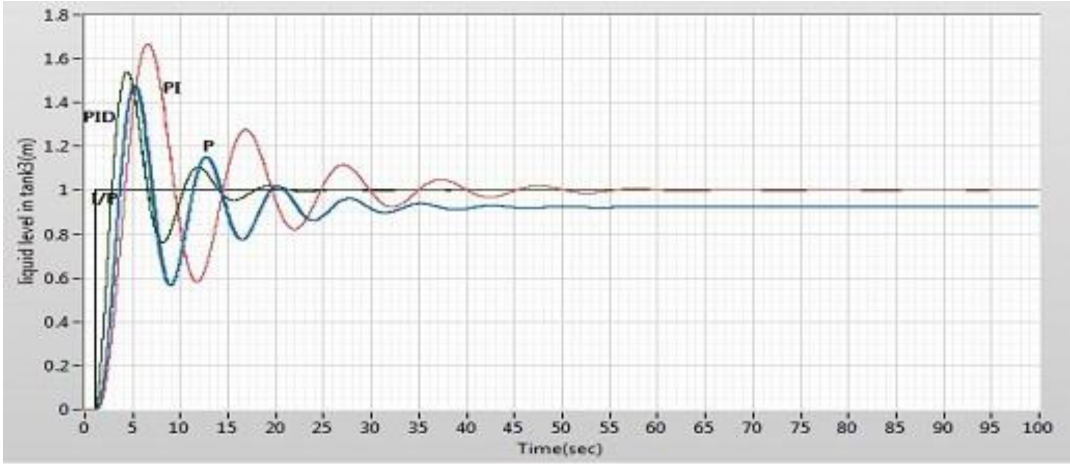

Fig. 21: Step response of three tank interacting process (CASE: III) using conventional PID controller

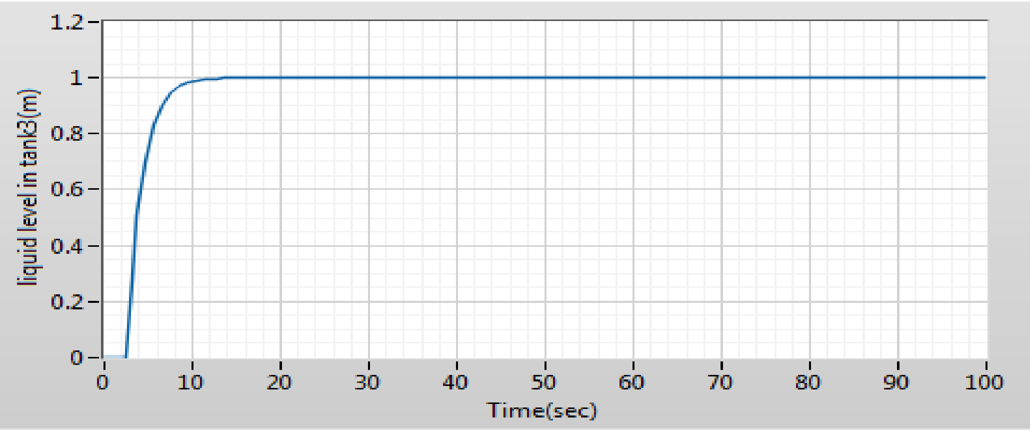

Fig. 22: Step response of three tank interacting process (CASE: III) using IMC controller

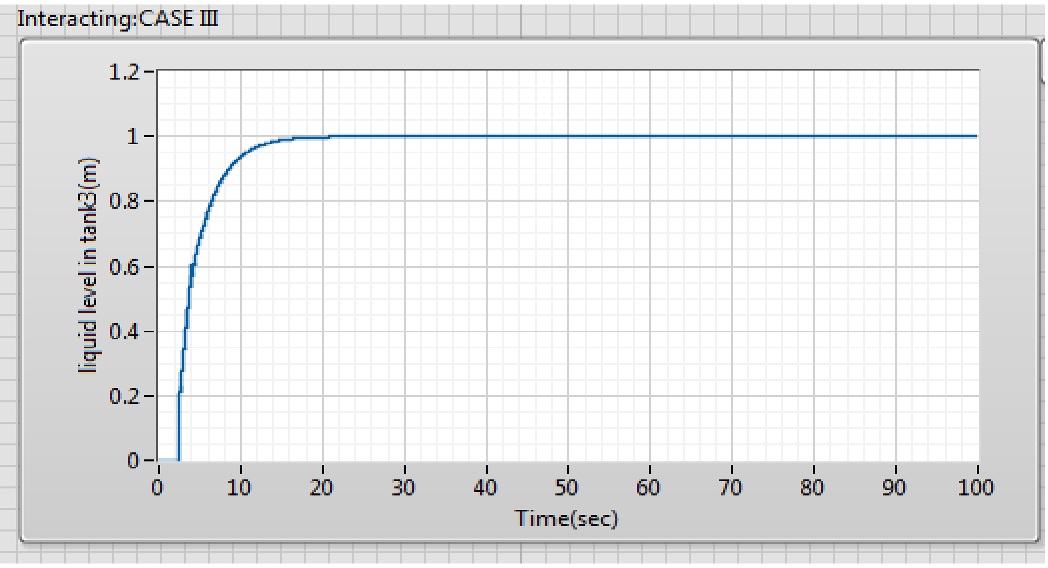

Fig. 23: Step response of three tank interacting process (CASE: III) using IMC-based PID controller

Result and Discussion

The overshoot and settling time of different combinations of three tank process are obtained from simulation results and are shown in Table 10.

Table 10: Maximum overshoot and settling time of different combinations of three tank process

S. No.	Type of Process	Type of Controller	Maximum Overshoot (in %)	Settling Time (in sec)
1.	Non-Interacting	P PI PID IMC IMC-PID	24 56 40 0 0	40 65 22 18 31
2.	Interacting: CASE I	P PI PID IMC IMC-PID	50 70 56 0 0	35 42 16 17 12
3.	Interacting: CASE II	P PI PID IMC IMC-PID	38 76 48 0 0	36 68 21 26 19
4.	Interacting: CASE III	P PI PID IMC IMC-PID	52 71 43 0 0	38 50 20 13 18

The performance of the P, PI, PID controller, IMC and IMC-based PID control scheme have been obtained using step input in LabVIEW. In Fig. 9, 13, 17, and 21, it is seen that P controller settles faster and has lower overshoot than PI controller but has offset error. PI controller has zero offset but has higher overshoot and settling time is also large. PID controller settles faster, has no offset error and has low overshoot. Therefore, most of the controller used in industries are PID controller instead of P and PI controller.

In simulation results shown in Fig. 10, 11, 14, 15, 18, 19, 22 and 23, IMC and IMC-based PID control is depicted. It is concluded that it has zero overshoot and zero offset error. Settling time can be decreased by increasing the filter coefficient in the controller. So, it can be maintained according to process requirements. IMC control scheme is more complex than conventional PID controller, so IMC is generally used in the process where overshoot is always required to be zero, otherwise PID control is implemented due to its simplicity and easiness in handling and tuning.

CHAPTER-4

CONCLUSIONS

4.1 Conclusions

4.2 Suggestions for Future Works

This chapter gives the conclusion of this project work and provides suggestions for future works.

4.1 Conclusions

This project consists of analysis of different tuning methods of PID controller for different kinds of process transfer function. Ziegler-Nichols method and Cohen-Coon methods are implemented on different types of transfer function. Ziegler-Nichols closed loop method cannot be implemented to any even order characteristic equation because of cancellation of gain constant. Ziegler-Nichols open loop method is only used to FODTP or first order process only. Higher order process cannot be controlled by Ziegler-Nichols open loop method.

IMC control has been applied on various combinations of three tank system and the results obtained are compared with those obtained using conventional feedback controller like P, PI and PID. The overshoot has decreased to zero as we apply IMC controller. The process performances can be varied by varying filter coefficient of the controller. As its value is increased, settling time and maximum overshoot decrease. It is also concluded that settling time decreases as we go from non-interacting to interacting process using PID controller. The settling time and maximum overshoot in three tank systems were analysed through computer simulation using LabVIEW software package.

4.2 Suggestions for Future Works

Future scope of this project work can include

- Exploring new tuning methods for perfect control of process.
- Implementation of controller in industries
- Designing suitable control strategy for level process.

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