Simulation of Zn Tuning Method for Adaptive PID Controller in Cylindrical Tank Level System Using Lab View

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Abstract: **In this paper, Adaptive PID controller model for cylindrical tank level control system using Lab VIEW software is performed. It aims at designing an adaptive control algorithm for a cylindrical tank system. System identification of the non-linear process is done using black box modeling and found to be First Order plus Dead Time (FOPDT) model. Here Proportional Integral and Derivative (PID) controller based on Ziegler Nichols method is designed initially and the results are compared with that of an Adaptive Controller. This designs a simulation system for conventional PID controller and Adaptive controller for cylindrical tank level control by Simulink in Lab VIEW software. Better controller performance and error can be minimized by using Adaptive controller than that of the ZN tuned PID controller.**

Keywords: **First Order plus Dead Time (FOPDT), ZN tuned PID controller, cylindrical tank system.**

I. INTRODUCTION

Control of industrial processes is a challenging task due to several reasons like nonlinear dynamic behavior, uncertain and time varying parameters, constraints on manipulated variables, interaction between manipulated and controlled variables, unmeasured and frequent disturbances, and dead time on inputs and measurements. A level that is too high may upset the reaction equilibrium, cause damage to equipment or result in spillage of valuable or hazardous material. If the level is too low, it may have bad consequences for the sequential operations. So control of liquid level is an important and common task in process industries. The majority of the control theory deals with the design of linear controllers with linear systems. PID controllers have proved to be a perfect controller for simple and linear processes.

Since the cylindrical tank is highly nonlinear, we make use of model reference adaptive controller to control the water level. The proposed method can adjust the controller parameters in response to changes and disturbances in the plant by referring to the reference model that specifies properties of the desired control system. In this work the process model is experimentally determined by using system identification technique. The method adopted here for system identification is step test and is done in real time with Lab VIEW using NI DAQ. The conventional controller tuning is accomplished using Zeigler Nichols based PID controller settings and the performances are compared with MRAC based on settling time and Integral Squared Error (ISE).

The software's and technology offers the potential to implement more advanced control algorithms but in industries they prefer a robust and transparent process control structure that uses simple controllers. That is why the PID controller remains as the most widely implemented controller despite of the developments of control theory.

II. PROCESS FOR CYLINDRICAL TANK LEVEL CONTROL SYSTEM

The control of liquid level and flow in the tank is a basic problem in process industries. Many times the liquid will be processed by chemicals or mixing treatments in the tanks, but the level of the fluid in the tanks must be controlled always. Controlling of liquid level is an important and common task in process industries. In this level process, the tank is in cylindrical shape in which the level of liquid is desired to maintain at a constant value. This is achieved by controlling the input flow into the tank. The control variable is the level in the tank and the manipulated variable is the inflow to the tank. These tanks find wide applications in process industries, namely hydrometallurgical industries, food process industries, concrete mixing industries and wastewater treatment industries.

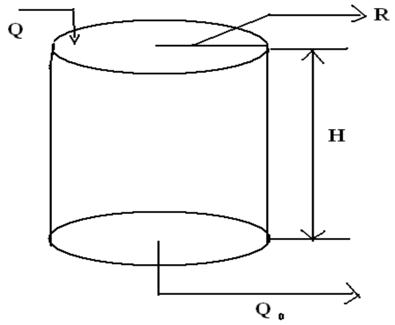

Fig: 1 Cylinder tank model

Nonlinear models are used where accuracy over a wider range of operation is required where they can be directly incorporated into control algorithms. Because of the inherent nonlinearity, most of the chemical process industries are in need of traditional control techniques. The nonlinear system taken up for the study is the cylindrical tank which finds wide application in process industries.

The control parameter chosen here is the level. Capacitance sensor and level transmitter arrangement senses the level from the process and sensed level is converts into corresponding electrical signal. Then electrical signal is fed to the current to voltage converter which in turn produces proportional voltage signal to the computer. In this level process, the tank is cylindrical in shape in which the level of liquid is desired to be maintained at a constant value .This is achieved by controlling the input flow into the tank. The control variable is the level in a tank and the manipulated variable is the inflow to the tank.

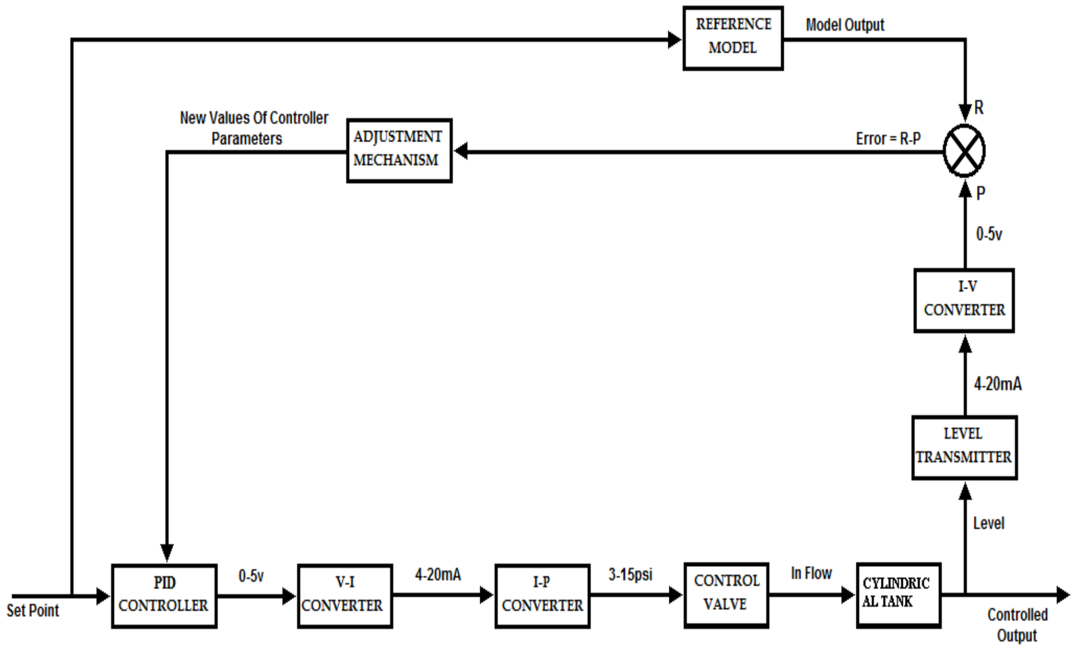

Fig: 2 Block Diagram for Closed Loop System

Figure 2 shows the block diagram of a closed loop system. The control system maintains water level in a cylindrical tank. The actual storage tank water level sensed by the level transmitter is feedback to the level controller & compared with a desired level to produce the required control action that will position the level control as needed to maintain the desired level. Now the controller decides the control action and it is given to the V/I converter and then to I/P converter. The final control element (pneumatic control valve) is now controlled by the resulting air pressure. This in turn controls the inflow to the cylindrical tank & the level is maintained.

III. PID CONTROLLER

The basic control loop can be simplified for a single-input-single-output (SISO) system as in Fig.3.3. Here any disturbance present in the system is neglected. When the characteristics of a plant are not suitable, they can be changed by adding a compensator in the control system. One of the simple and useful compensators feedback control design is described in this section. In this project the control method is designed based on the time-dimension performance specifications of the system, such as settling time, rise time, peak overshoot, and steady state error and so on.

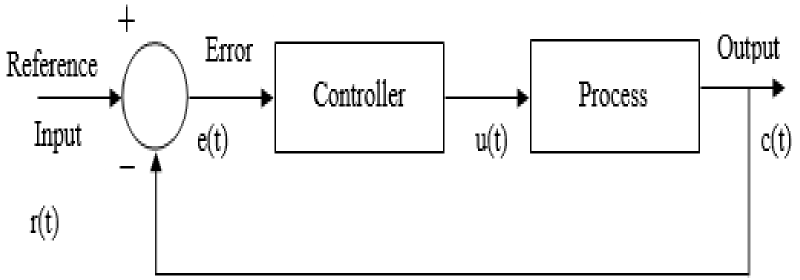

Fig: 3 Closed Loop SISO Systems

The controller may have different structures. Different design methodologies are used for designing the controller in order to achieve desired performance level.

Now, four types of controllers are considered as follows:

A. PROPORTIONAL CONTROLLER:

A proportional control system is a type of linear feedback control system. Proportional control is how most drivers control the speed of a car. In other words, the output of a proportional controller is the multiplication product of the error signal, which is the difference between the set point and the proportional gain.

This can be mathematically expressed as

$$P_{out} = k_P e(t)$$

Where

P_{out} - Output of the Proportional controller

K_p - Proportional gain

e(t) - Instantaneous process error at time 't'

e(t) = SP – PV

SP - Set point

PV - Process variable

With increase in K_p

i. Response speed of the system increases

ii. Overshoot of the closed-loop system increases c

iii. Steady-state error decreases

But with high $K_p$value, closed-loop system becomes unstable.

B. INTEGRAL CONTROL:

In a proportional control of a plant whose transfer function does not possess an integrator 1/s, there is a steady-state error, or offset, in the response to a step input. Such an offset can be eliminated if integral controller is included in the system. In the integral control of a plant, the control signal, the output signal from the controller, at any instant is the area under the actuating error signal curve up to that instant. But while removing the steady-state error, it may lead to oscillatory response of slowly decreasing amplitude or even increasing amplitude, both of which are usually undesirable.

C. PROPORTIONAL-PLUS-INTEGRAL CONTROLLERS:

In control engineering, a PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled by a weighted sum of the error (difference between the output and desired set-point) and the integral of that value. It is a special case of the PID controller in which the Derivative (D) part of the error is not used.

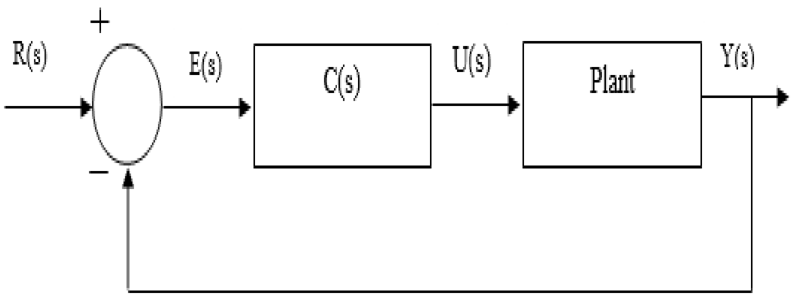

Fig: 3 Block diagram of controller plant model

Integral control action added to the proportional controller converts the original system into a higher order system. Hence the control system may become unstable for a large value of Kp since roots of the characteristic equation may have positive real part. In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady-state error in response to various inputs. As the value of Ti is increased the following actions take place in PI controller:

i. Overshoot tends to be smaller

ii. Speed of the response tends to be slower

D. PROPORTIONAL-PLUS-DERIVATIVE CONTROLLERS:

Proportional-Derivative or PD control combines proportional control and derivative control in parallel .Derivative action acts on the derivative or rate of change of the control error. This provides a fast response, as opposed to the integral action, but cannot accommodate constant errors (i.e. the derivative of constant non-zero error is 0). Derivatives have phase of +90degrees leading to an anticipatory or predictive response. However, derivative control will produce large control signals in response to high frequency control errors such as set point changes (step command) and measurement noise. In order to use derivative control the transfer functions must be proper. This often requires a pole to be added to the controller.

E. PROPORTIONAL-PLUS-INTEGRAL-PLUS-DERIVATIVE CONTROLLERS:

PID control is the method of feedback control that uses the PID controller as the main tool. The basic structure of conventional feedback control systems is shown in Figure below, using a block diagram representation. In this figure, the process is the object to be controlled. The purpose of control is to make the process variable *y* follow the set-point value *r*. To achieve this purpose, the manipulated variable is changed at the command of the controller. As an example of the process, a heating tank in which some liquid is heated to a desired temperature by burning fuel gas can be considered.

In some applications, however, a major disturbance enters the process in a different way, or plural disturbances need to be considered.

The error *e* is defined by

$$e = r - y$$

The compensator *C*(s)is the computational rule that determines the manipulated variable *u* based on its input data, which is the error *e* in this case. The last thing to notice about this example is that the process variable *y* is assumed to be measured by the detector, with sufficient accuracy instantaneously that the input to the controller can be regarded as being exactly equal to *y*. When used in this manner, the three elements of PID produce outputs with the following nature:

i. P element : Proportional to the error at the instant *t*, this is the present error

ii. I element: proportional to the integral of the error up to the instant

t, which can be interpreted as the accumulation of the past errors

iii. D element: proportional to the derivative of the error at the instant

t, which can be interpreted as the prediction of the future error.

F. PID RESPONSE CURVES:

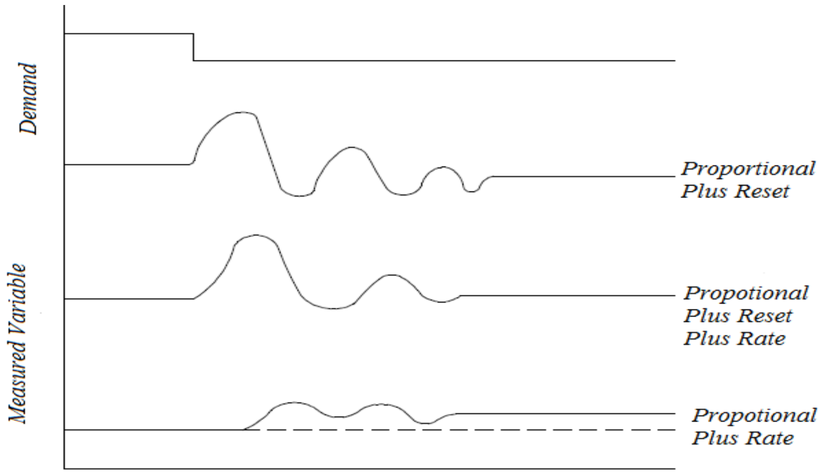

Fig: 4 PID response curves

The above figure demonstrates the combined controller response to a demand disturbance .The proportional action of the controller stabilizes the process.

G. ZIEGLER-NICHOLS TUNING:

Ziegler-Nichols formulae for specifying the controllers are based on plant step responses. Ziegler-Nichols tuning is used for P, PI and PID controllers. It has to be noted that controllers tuned using this procedure are tuned for control, not tracking. Thus, controllers with parameters tuned according to Ziegler-Nichols recommendation will perform well in disturbance rejection, but it will perform poorly in tracking reference changes.

Steps to determine PID controller parameters:

Table I to Determine PID controller parameters

PI Type	**KP**	**TI**	**TD**
P	0.5Kc	INFINITY	0
PI	0.45Kc	P c /1.2	0
PID	0.6Kc	Pc /2	Pc /8

i. Reduce the integrator and derivative gains to 0

ii. Increase Kp from 0 to some critical value Kp = Kc at which sustained oscillations occur

iii. Note the value Kc and the corresponding period of sustained oscillation, Pc

Let us consider that the overall system has a unity feedback.

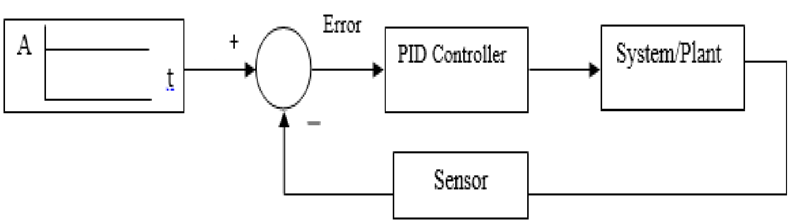

Fig: 5 PID Controller in closed loop system

The behavior of the parameters is as follows

Table II Response of PID Closed loop system

Response	Rise Time	Overshoot	Settling Time	S-S Error
K_P	Decrease	Increase	Small Change	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	Small Change	Decrease	Decrease	Small Change

Typical steps for designing a PID controller are

i. Determine what characteristics of the system need to be improved

ii. Use K_P to decrease the rise time

iii. Use K_D to reduce the overshoot and settling time

iv. Use K_I to eliminate the steady-state error

Changes in system's closed loop response because of the changes in PID parameters with respect to a step input can be best described using the following chart.

Ziegler and Nichols conducted numerous experiments and proposed rules for determining values of K_P, K_I and K_D based on the transient step response of a plant. They proposed more than one method, but it can be limited to the first method of Ziegler-Nichols. It applies to plants with neither integrator nor dominant complex-conjugate poles, whose unit-step response resembles an S-shaped curve with no overshoot. This S-shaped curve is called the reaction curve.

IV. SYSTEM IDENTIFICATION

The process considered here is a cylindrical tank system in which the level of the liquid is desired to maintain a constant value. This can be achieved by controlling the input flow rate into the tank. Here q is the inlet flow and qo is the outlet flow.

MATHEMATICAL MODELING:

The Mathematical modeling is done by considering the below parameters

ρ = density of the liquid in the system Kg/cm^3

$\rho 1$ = density of the liquid in the inlet stream Kg/cm^3

$\rho 2$ = density of the liquid in the outlet stream Kg/cm^3

V = total volume of the cylindrical tank

q = volumetric flow rate of the inlet stream LPH

q_o = volumetric flow rate of the outlet stream LPH.

R = maximum radius of the tank

r = radius of the tank at steady state

H = maximum height of the tank

h = height of the tank at steady state

Using the law of conservation of mass

$$\left[\frac{\text{Accumulation of total mass}}{\text{time}}\right] = \left[\frac{\text{input of total mass}}{\text{time}}\right] - \left[\frac{\text{output of total mass}}{\text{time}}\right]$$

$$\frac{dv}{dt} = \rho 1 q(t) - \rho 2 q_0(t)$$

Assuming the room temperature as constant, the density of water is same throughout.

Therefore $\rho 1 = \rho 2 = \rho$

$V = \frac{1}{3}\pi \frac{R^3}{H^3} h^3$

Applying the steady state values, and solving the equations (2.4) and (2.5), for linearizing the non - linearity in the cylindrical tank,

$\frac{H(S)}{Q(S)} = \frac{kp}{\tau s+1}$ $\quad$ $G(S) = \frac{H(S)}{Q(S)} = \frac{1.61066}{168S+1}$

The proportional gain K_p , integral gain K_i are calculated using Ziegler-Nichols method

K_P = R = 0.6*K_C

Kc represents ultimate gain of response,

$K_c = \frac{1}{M}$

Where, M is amplitude ratio of the system response, here M is 0.0698 dB.

K_C = 14.327

To determine the proportional gain K_P,

K_P = 0.6*14.327

K_P = 8.595

Integral gain $K_I = K_P/TI$

$T_I = P_C/2$

Where, $P_C = 2\pi/\omega_{co}$

From response cross over frequency ω_{CO} is 0.1166 rad/sec

P*c* = 53.908 min/cycle

T_I = 26.954

Sub the T_I value in $K_I = K_P/T_I$

K*I* = 8.595/26.954

K_I = 0.3188

Derivative gain K*D*=K*P**T*D*

$T_D = P_C/8$

T_D =53.908/8

T_D=0.673

Sub the above values in $K_D = K_I * T_D$

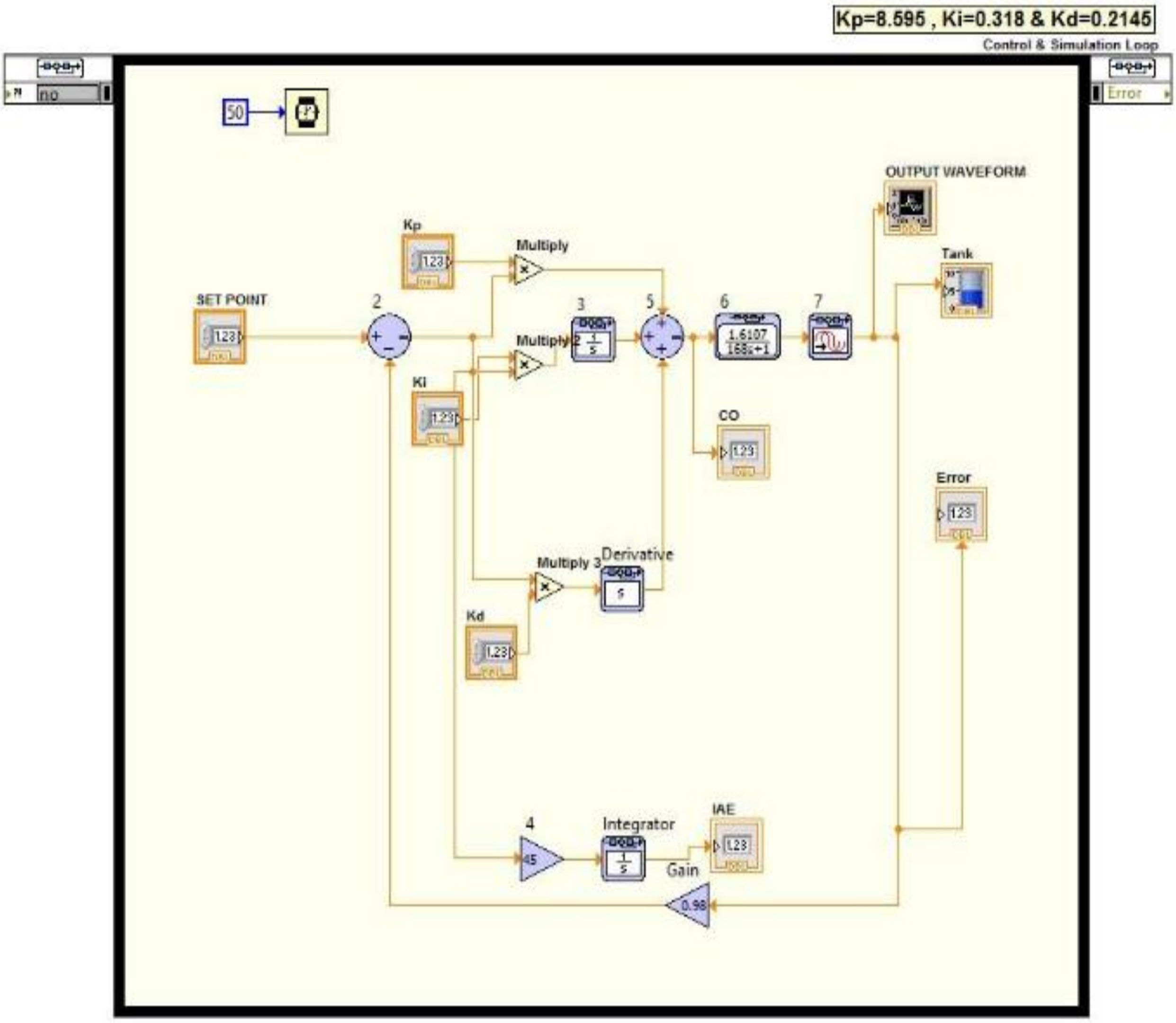

Fig:6 Block Diagram Window for

MRAC Controller

K_D=0.3188*0.673

K_D=0.2145

i. Note down t2

ii. Then time constant τ = t2 – t1

iii. Process gain K_P is ΔPV/ΔV where ΔV is change in the input in volts

At a fixed inlet flow rate, outlet flow rate, the system is allowed to reach the steady state. After that a step increment in the input flow rate is given and various readings are noted till the process becomes stable in the cylindrical tank. The experimental data are approximated to be a FOPDT model.

$$G(S) = \frac{1.61066}{168S+1}E^{-22.9S}$$

V. RESULTS AND SIMULATIONS

The Adaptive Control is designed and the response of the process obtained. The performance of the proposed control strategy is found to be quite satisfactory for a particular set point. The result to MRAC is compared with conventional PID controller as follows.

A. FRONT PANELRESPONSE FORCONVENTIONALPIDCONTROLLER:

Response of conventional PID controller shows 30cm height to liquid level is maintained in cylindrical tank. Here, it is possible to manually adjust the controller parameters such as K_P, K_I&K_D.

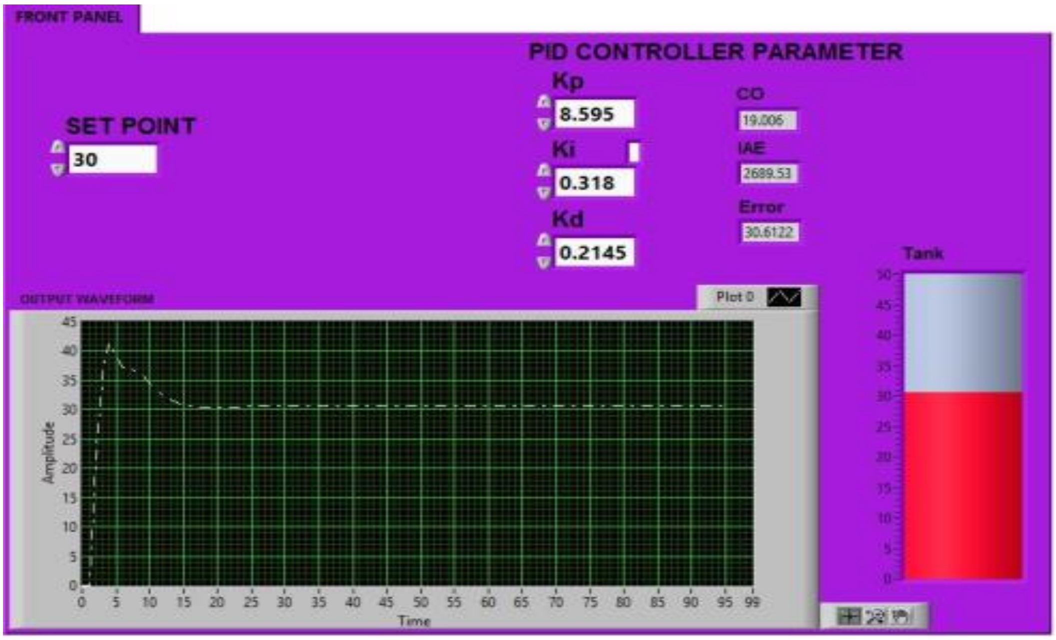

Fig: 7 Front Panel for Conventional PID controller

Proportional control is used to reduce and eliminate the present error, integral control is used for reducing the past error and derivative controller is used for fast responses. So a very small value has to be given to integral parameter (K_I) and the proportional parameter (K_P) has to be adjusted until the desired level of the cylindrical tank is reached. It has to time taken for settling and rise.

B.BLOCKDIAGRAMWINDOWFOR MRACCONTROLLER:

The block diagram window represents the simulation for model reference adaptive controller. Simulation subsystem of adaptive controller is inside of control and simulation loop. The tracking error, which is generated by comparing the plant output with the reference model output, represents the deviation of the plant output from the desired trajectory.

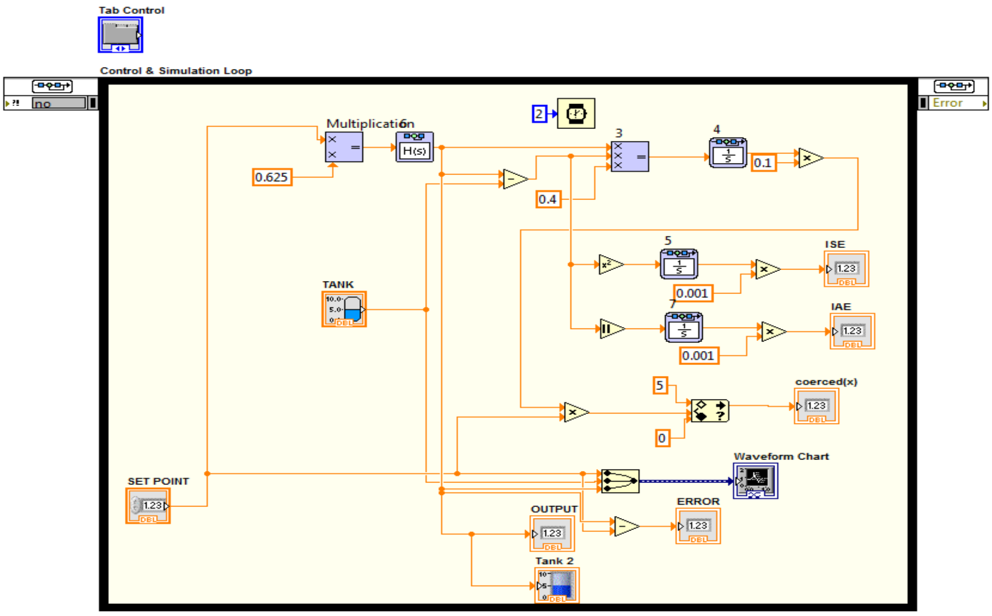

Fig: 8 Block Diagram Window for MRAC Controller

The closed loop plant is made up of an ordinary feedback control law that contains the plant and a controller and an adjustment mechanism that generates the controller parameter estimates on-line. The reference model is an ideal model and its output. Here the actual output is compared with reference output. The comparison error has to be rectified by adjustment mechanism of the PID controller.

Table IV Comparative results of performance indices

Controller	ISE	IAE
PID	11397.2	7967.8
MRAC	2463.7	1729.8

VI. CONCLUSION

The nonlinearity of the cylindrical tank is analyzed. Many process industries use cylindrical tanks because of its shape contributes to better drainage of solid mixtures, slurries and viscous liquids. The basic functions of a PID controller have been explained. Most of the industrial controllers are PID in nature. The major reasons behind the popularity of the PID controller are its simplicity in structure and the applicability to variety of processes. Moreover the controller can be tuned for a process, even without detailed mathematical model of the process.

However, proper tuning of the controller parameters requires extensive experimentation. Conventional proportional integral derivative (PID) controller based on Ziegler Nichols (ZN) method and model reference adaptive controllers are designed in Lab VIEW software.

The Adaptive Control is designed and the response of the process is obtained. The performance of the proposed control strategy is found to be quite satisfactory for set point. The result of MRAC is compared with conventional PI controller. The results show that better controller performance and error is minimized in the model reference adaptive controller. Controller performance and error can be minimized by using MRAC than that of the ZN tuned PI controller.

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