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Article

Real-Time Level Control of Spherical Tank Process using Gain Scheduled PID Controller

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I N F O

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A B S T R A C T

The objective of this paper is to maintain the level inside the process tank in a desired value. The real time implementation of the process is designed and implemented in MATLAB. Gain scheduled PID controller is designed to enhance the performance of the conventional PID controller for nonlinear spherical tank process. It is based on linearization of the nonlinear model around selected operating points. The linear design methods are applied at each region in order to arrive at a set of linear control laws.

Keywords: Spherical Tank, Gain Scheduled PID Controller, Conventional PID Controller

Introduction

Spherical tank systems are used to hold liquids, compressed gases which is not typically labelled or regulated as a storage tank. Spherical tanks have greater advantages compare to conical tank system while washing and it is intensified production and the cost is also less compared to the conical tanks. It gives a non-linearity because of its change in shape. Level response of Spherical tank varies with its volume geometry. The tuning of level controllers can be challenging because of the extreme variation in the process dynamics and tuning settings. Generally, PID controller is suitable for to obtain a desired response. The conventional Proportional - Integral - Derivative (PID) is commonly utilized in controlling the level, but the parameter is not enough for efficient control. This work endeavors to design a system using a gain scheduling method of obtaining controller parameters. The gain scheduling controller improves the quality of control action. When deriving a simple model to be used for PID controller tuning, it is important to ensure that the model describes the process well for the typical input signal is obtained during the process operations model accuracy may be poor if the process is non-linear. Adaptive control is a control method in which the controller parameters are adapted based on the variation in model parameter. Hence this controller is capable of handling non-linear and time varying process. In many situations it is known how dynamics of the process change with operating condition of the process. First source for change in dynamics may be due to non-linearity that are known. It is possible to change parameters of controller by monitoring operating conditions of the process. In this paper, experimental studies are carried out on the laboratory spherical tank process. The closed loop performance of this process by employing the proposed controllers are observed through simulation studies and a comparative analysis is carried out using MATLAB/ SIMULINK software.

Process Description

The labeled photograph of the conical & spherical tank level process trainer is illustrated in Figure 1. It consists of conical and spherical process tanks fitted with a level transmitter and necessary drain valve arrangements. The inlet flow to the tank is controlled by a control valve which operates on a 3 to 15 psi pressure signal. A current to pressure (I/P) converter is used to convert the output of the controller (4-20mA) to the signal pressure.

The process parameter is controlled by a digital indicating controller. These units along with necessary piping are fitted on the support frame. The setup is designed for tabletop placement and access. The controller is connected to computer through USB for monitoring and controlling the process. User friendly software will be supplied along with the hardware to perform different set of experiments. The P&ID of the conical & spherical tank level process trainer is shown in Figure 2 and Schematic diagram is shown in Figure 3.

The mass balance equation of tank is given in Equation 1. The rate of change of liquid volume in tank is equal to the net flow of liquid into the tank. The volumetric inflow rate of the inlet stream and outlet stream are F^1 and F^2. Height of the spherical tank is h.

$$A\left(\frac{dh}{dt}\right) = F1 - F2 \tag{1}$$

$$\text{Let } F2 = \frac{h}{R} \ (R = \text{valve resistance})$$

$$A\left(\frac{dh}{dt}\right) = F1 - \frac{h}{R}$$

$$AR\left(\frac{dh}{dt}\right) = RF1 - h$$

$$AR\left(\frac{dh}{dt}\right) + h = RF1 \tag{2}$$

Figure 1.Labelled Photograph of The Conical & Spherical Tank Level Process Trainer

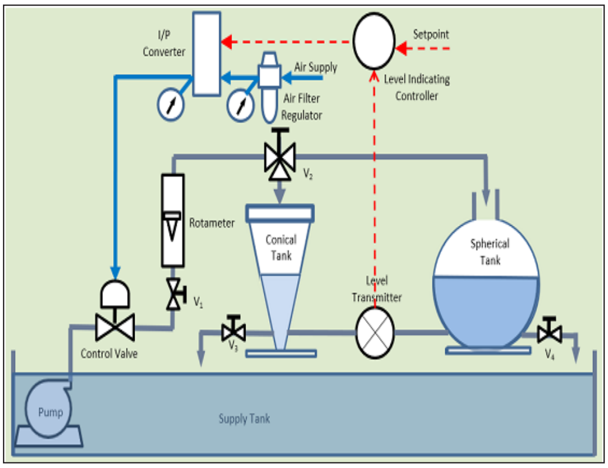

Figure 2.P&ID of the Conical and Spherical Tank Level Process Trainer

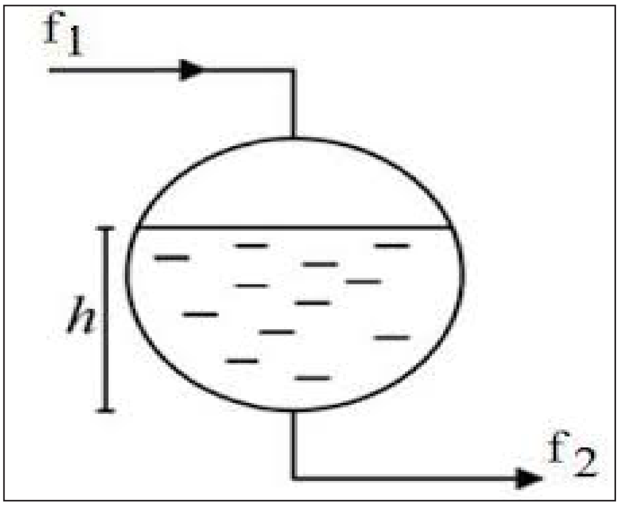

Figure 3.Schematic Diagram of Spherical Process Tank

Taking laplace transform in equation (2) on both sides, we get

$$\tau sh(s)+h(s)=RF1(s) \tag{3}$$

Rearranging the equation (3),

$$h(s) = \frac{R}{\tau s + 1} F1(s) \tag{4}$$

The equation (4) describes the mathematical model for a conical tank level control and this equation is implemented in MATLAB and to obtain open loop response.

Table 1.Process Parameters

Parameter	Value
Diameter of spherical tank (D)	250 mm
Total Height of the spherical tank (H)	250 mm
Inlet flow rate to the tank (F1)	100 LPH

The Figure 4, shows the real time implementation of open loop response of the spherical process tank. It has the time delay of 2 seconds. The level settles at 52cm. It has some oscillation due to some external noise/ disturbance.

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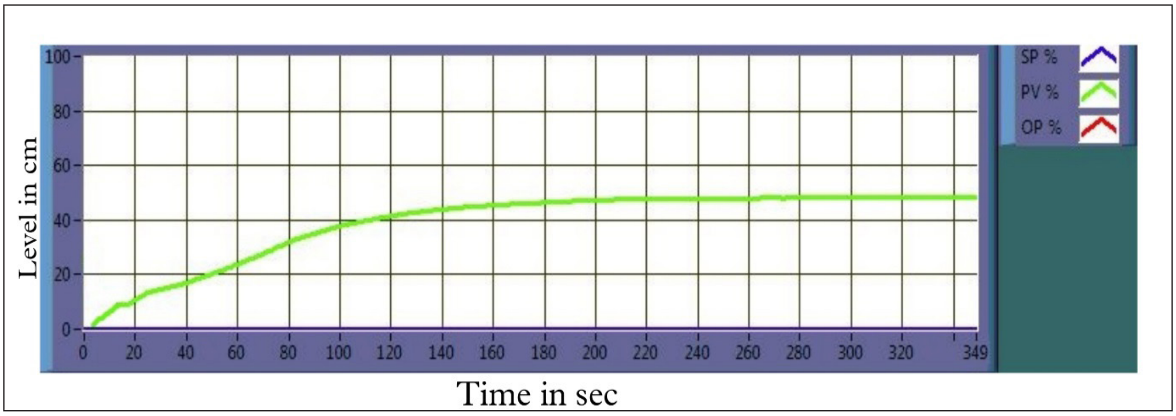

Figure 4.Real Time Implementation of Open Loop Response of The Spherical Process Tank

From the open loop response the transfer function is obtained. The transfer function of the spherical level process tank is obtained as,

$$G(s) = \frac{0.438}{69S+1} e^{-2s} \quad (5)$$

PID Controller Design and Tuning

The PID controller is simple and robust and hence widely used in most of the process industries. The controller parameters can be tuned using Cohen-Coon method. The Table 2, shows the required gain values of the spherical process tank.

Table 2.Tuning Parameters

Type	K_p	T_i	T_d
P	1.2574	-	-
PI	1.4068	6.2813	-
PID	0.9472	4.8631	0.7234

Simulation of PID Controller

The design and simulation of PID controllers with identified models are performed using MATLAB. Figure 5, shows the simulation diagram of PID response of spherical process tank. Figure 6, shows the simulated response of PID controller of spherical process tank.

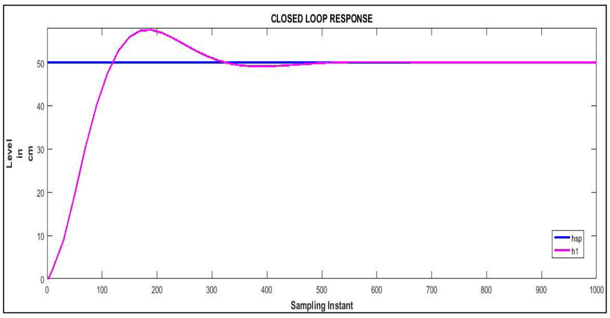

Figure 6.Closed Loop Response of Spherical Tank Process

In Figure 6, the legend h1 is PROCESS VALUE and the hsp is SET Value. The PID controller response of Spherical tank process has same overshoot and same undershoot in PV. And then the level settles in the SV of 50 cm at the sampling instance of 90 sec.

Design of Gain Scheduling Controller

Gain scheduling is a method widely applied in industrial practice to control processes where large changes of the operating conditions can occur in its standard implementation. The Gain-scheduling which is a well known technique of industrial control and it is employed when a plant is subject to large changes in its operating state, a situation that is typical in industry.

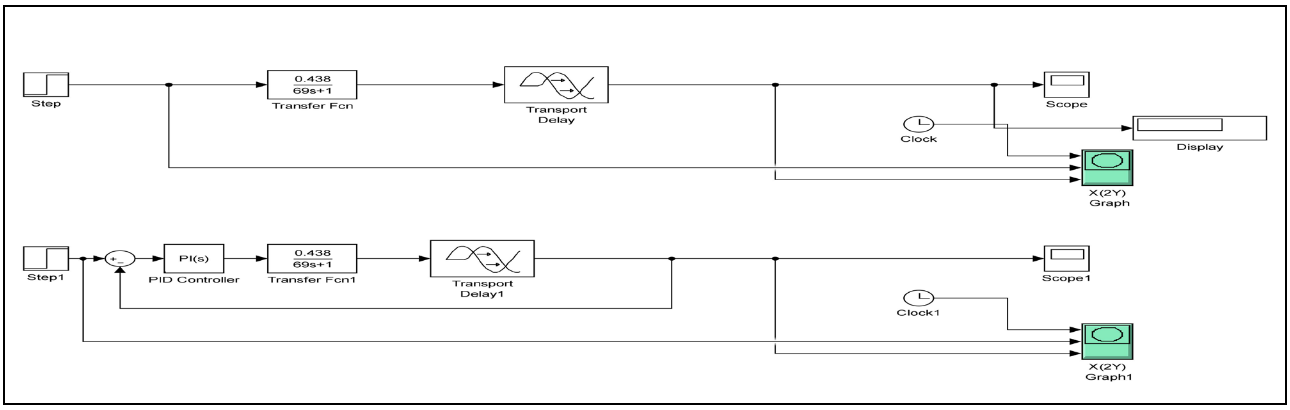

Figure 5.Simulink Model of PID Controller for Spherical Tank Process

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Large changes in the operating state leads to corresponding variations in the parameters of the linearized models of the plant about these operating states. It is well known that it is not possible therefore to design a controller to operate satisfactorily at one operating state and expect it to perform equally well elsewhere without re-tuning it. Gain scheduling is utilized in controlling the level of the process tank in presence of set point changes.

Gain Scheduling PID Controller

Most of basic PID controller tuning methods are heuristic so that it does not guarantee optimal control trajectory of set point change. The model structure is offered based on polynomial controller method. Data fitting is important. Gain Scheduler method maps the set point information as the inputs to the Proportional gain (K_p), Integral gain (Ki) and Derivative gain (K_d) as the outputs. The structure of Gain Scheduler is demonstrated in Figure 7.

The drive signal is generated by multiplying the error with a special signal so that it is capable of changing the process variable to reach the target or set point. This special signal is derived from the reference signal which is the same for all scheduling variable that can be described by polynomial operators with coefficients. The drive signal u is generated so that the output signal will meet the target (set point) at the end of the interval in a smooth trajectory without overshoot or oscillation.

Simulation of Gain Scheduling Controller

The design and simulation of GS-PID controller with identified models are performed using MATLAB. Figure 8 shows the simulation diagram of GS-PID controller of spherical process tank.

Figure 9 shows the simulated response of GS-PID controller of conical process tank. The level settles in the SV of 50 cm at the sampling instance of 65 sec.

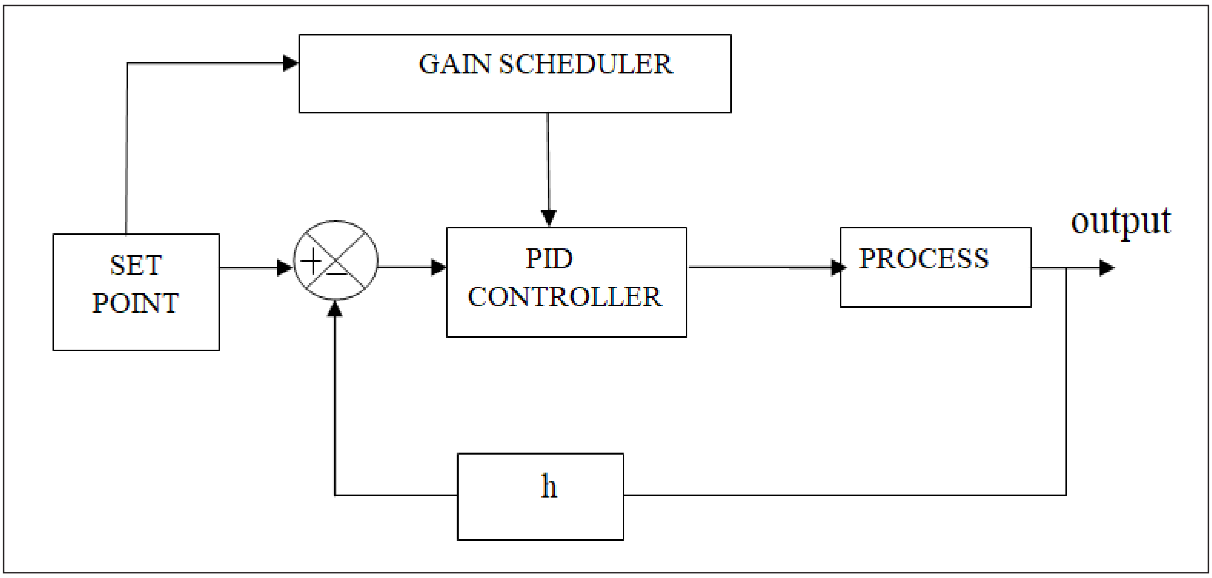

Figure 7.Structure of Gain Scheduling PID Controller

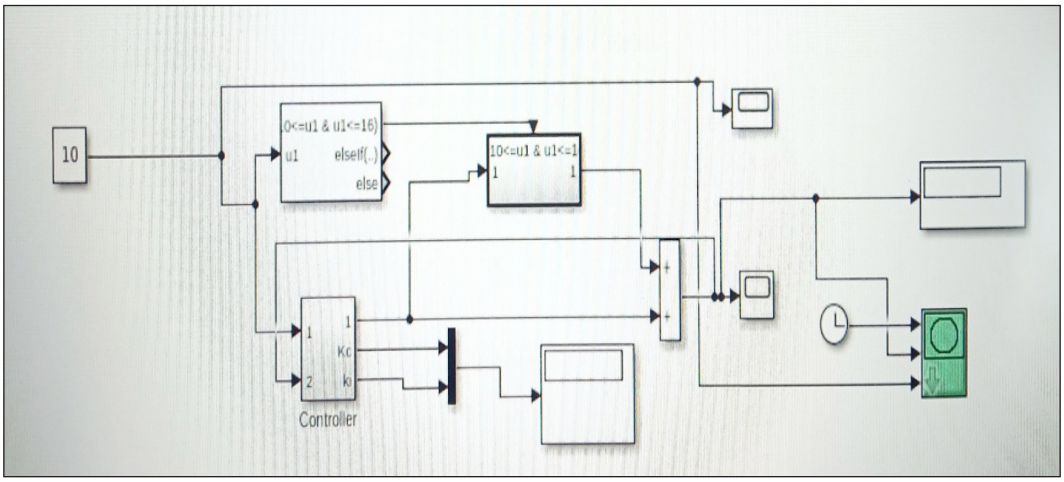

Figure 8.Simulation Diagram of GS-PID Controller

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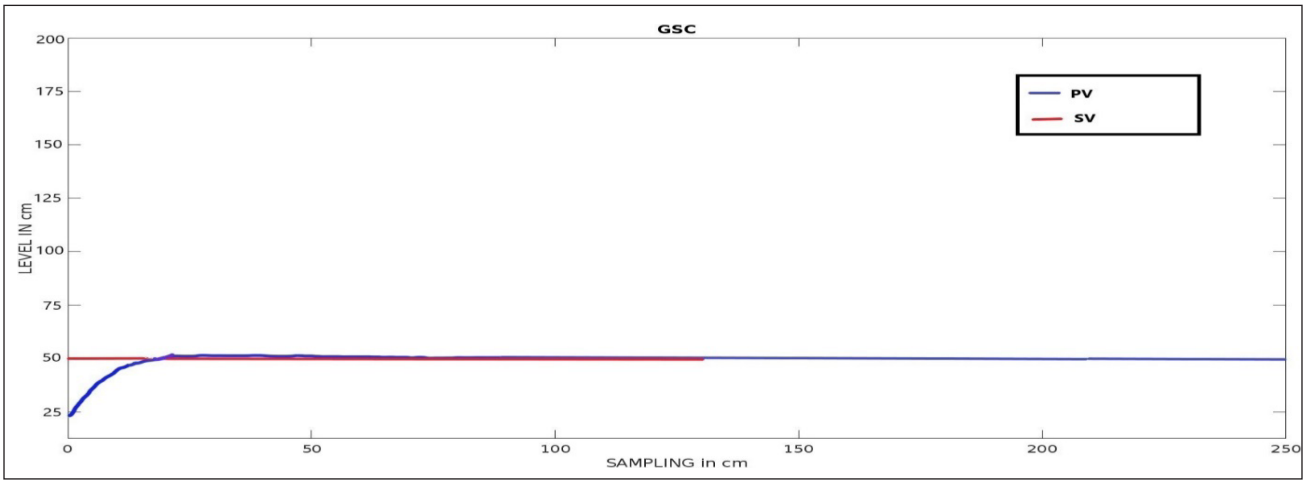

Figure 9.Response of GS-PID Controller

Real Time Implementation of PID and Gain Scheduling - PID Controllers

The real time implementation of the Spherical process tank of the PID and GS-PID controllers are implemented and the simulation and the real time implementation of the conical process tank of the Open loop, PID and GS-PID controllers are compared. Figure 10 shows the real time implementation of the PID controller of the Spherical process tank.

In Figure 10, the response has the time delay of 15 seconds. The level settles at 50cm at the sampling instance of 105 seconds. Here the legend PV is process value, the SV is the set value and the OP is the output percentage. Figure 11 shows the real time implementation of the GS-PID controller of the spherical process tank.

In Figure 11, the response has the time delay of 4 seconds. The level settles at 50cm at the sampling instance of 57 seconds. Here the legend PV is process value, the SV is the set value and the OP is the output percentage.

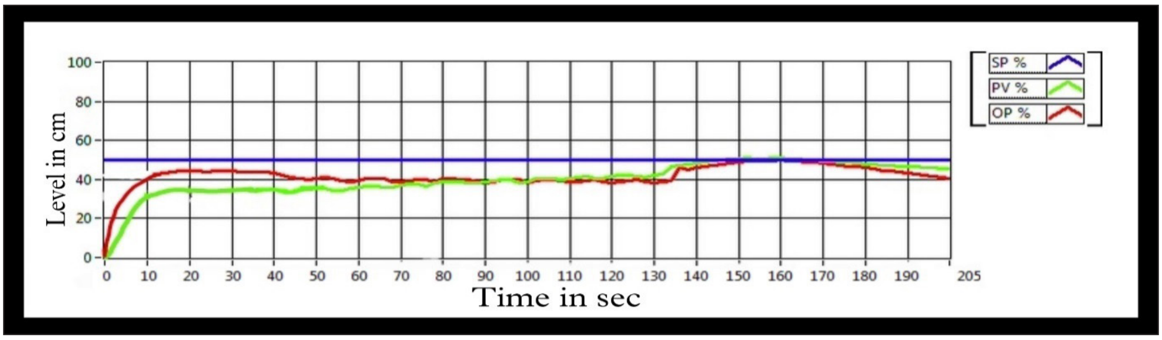

Figure 10.Real Time Implementation of PID Controller

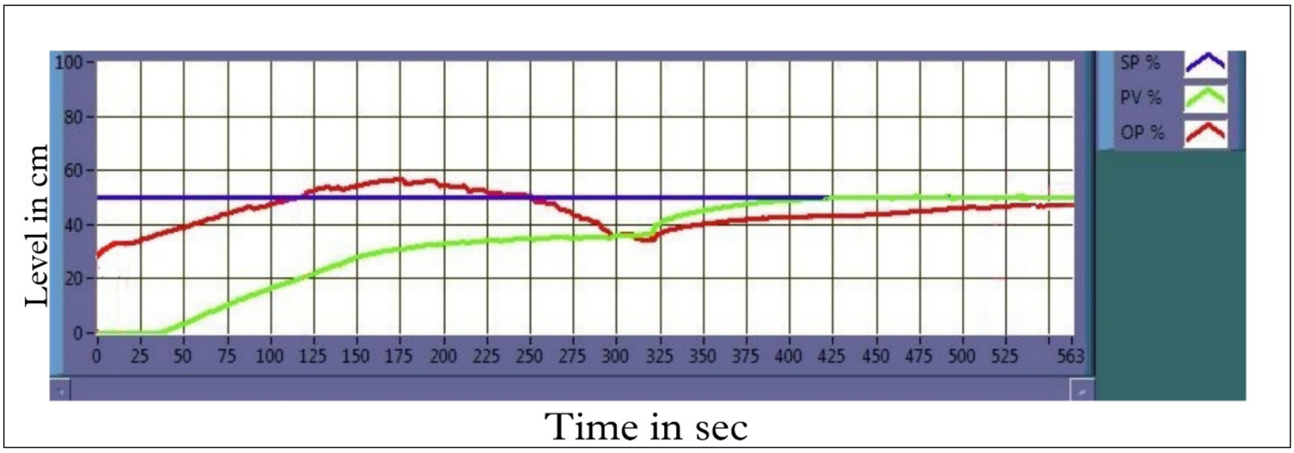

Figure 11.Real Time Implementation of the GS-PID Controller

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Result and Discussion

Comparative performance analysis of the real time implementation and simulation of open loop response of the conical process tank are done and the results are tabulated based on the settling time, setting level and time delay. Table 3, shows comparison of open loop responses of the spherical process tank.

Table 3.Comparative Performance Analysis of Open Loop System

Open loop System	Time Delay (seconds)	Settling Level (cm)	Settling Time (seconds)
Simulation	7	64	40
Real time Implementation	7	52	560

Comparative performance analysis of the real time implementation and simulation of PID controller of the spherical process tank are done the results are tabulated based on the settling time, setting level and time delay. Table 4, shows the Comparative performance analysis of simulation and real time implementation of PID control of the spherical process tank.

Table 4.Comparative Performance Analysis of PID Controller

PID Controller	Time Delay (seconds)	Settling Level (cm)	Settling Time (seconds)
Simulation	7	50	88
Real time Implementation	15	50	113

Table 5.Comparative Performance Analysis of GS-PID Controller

GS-PID Controller	Time Delay (seconds)	Settling Level (cm)	Settling Time (seconds)
Simulation	0	50	61
Real time implementation	2	50	52

Table 6.Comparative Analysis of the Performances of PID Controller and GS-PID Controller

Controller	Settling level (cm)	Settling time (seconds)	ISE	IAE
PID Controller	50	113	95	88
GS-PID Controller	50	52	50	42

Comparative performance analysis of the real time implementation and simulation of GS-PID controller of the spherical process tank are done and the results are tabulated in Table 5, based on the settling time, setting level and time delay.

Table 6, shows the comparative analysis of the performances of PID controller and GSC of the spherical process tank. It has settling time, ISE and IAE of the PID controller and GSC of the conical process tank. From the table 6, Settling level of PID and GS-PID are same (50 cm), Settling time of PID is 113 seconds whereas GS-PID is 52 seconds, ISE of PID is 95 whereas GS-PID 50 and IAE of PID is 88 whereas GS-PID is 42. The real time response and simulation response of the PID and GS-PID is compared and it is proved that the controller implemented using gain scheduling adaptive controller performs well compared to conventional PID controller.

Conclusion

From the open loop response, the PID controller using Cohen and Coon method is designed and simulated and also the Gain Scheduling PID controller is designed and simulated. The real time response and simulation response of the PID and GSPID is compared and the comparative analyses of the performances of these controllers are also carried out in this work. Based on the comparative analyses GSC based PID controller has better settling time and low ISE values when compared to normal PID controller.

Scope of the Future work

The PID and GSPID controllers for interacting spherical tank system can be done both real time and simulation. Also intelligent controller can be implemented for the chosen process using soft computing techniques.

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