ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 3, Issue 5, May 2015

Performance Analysis of Sliding Mode Control method with a PID Controller for a Nonlinear System

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Abstract: Accurate and quick control of parameters is required in this day and age for smooth and efficient production of products in industries. For this, the Sliding Mode Control (SMC) method for a non-linear system is proposed in this paper. The non-linear system considered in this paper is a Single-Input Single-Output (SISO) conical tank. A mathematical model is obtained for the given system and then the sliding surface is developed using the Lyapunov analysis. Simulation is then done for the PID controller and also for the proposed SMC method and then the performance index for both is compared. It is seen that SMC shows better performance compared to PID controller.

Keywords: SMC, SISO, Lyapunov analysis, PID controller.

I. INTRODUCTION

Chemical industries, food processing industries, pharmaceutical industries, manufacturing plants, metallurgical industries utilize non-linear systems such as conical tanks as they do not let the sediments to settle and easily drains out the slurries. However, non-linearity occurs due to its shape.

Conventional controllers such as Proportional-Derivative (PD), Proportional-Integral (PI), and Proportional-Integral-Derivative (PID) controllers are mostly used in the industries as they are convenient, simple and familiar. However, they present many problems such as in the case of PI controllers, the system does not completely settle and has start-up overshoot. For PD controllers, offset errors will not be eliminated and for PID controllers, overshoots occur and system takes a while to settle and the controller is not robust and very accurate.

Control algorithms like Model Predictive Control (MPC) and Internal Model Control (IMC) require models of the given system. However, accurate modelling of the system is not possible. Furthermore, if there is model uncertainty, these controllers must be detuned. As we know, if the controller is stable, and the process is stable, then the overall system is stable [1]. Hence the controller designed must be stable.

II. PROPOSED WORK

System identification is the process of constructing a mathematical model for a dynamic system based on set of measured stimulus and response samples. An accurate model can be used in off-line controller design and implementation of advanced control schemes.

In this work, the system identification of a non-linear system is done using OLT (Open Loop Test) method. In this work, the real time conical tank system was used for collecting the input and output data. The system includes the level transmitter, rotameter, Current-to-Pressure converter (I-P converter), control valve, pump, compressor and reservoir tank. In addition to this Data Acquisition Card (DAC), Voltage - to - current converter (V-I converter), current-to-Voltage converter (I-V converter) and a computer are used. The block diagram is shown in Figure 1.

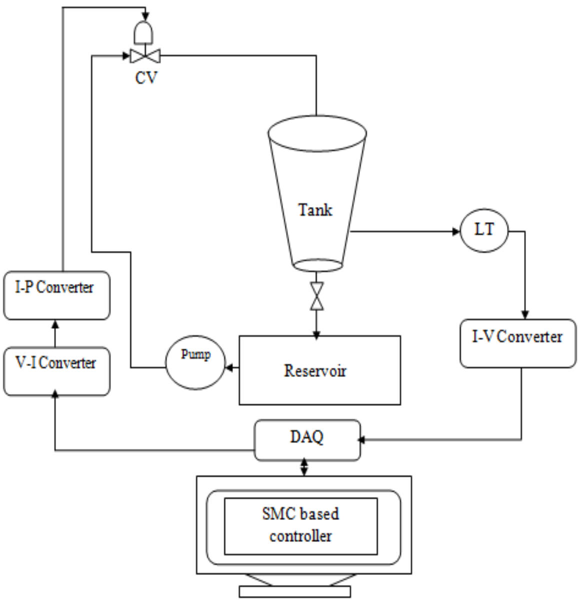

Figure 1: Schematic diagram of the system

The conical tank used in the given system is non-linear due to its shape. Its shape is broad at the top and becomes narrower at the bottom. Hence a controller must be designed to maintain the process level at desired set-point by rectifying the disturbances.

The specifications are indicated in Table A .All the components listed must function to their efficiency and their interface must also be proper without any disturbance

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TABLE I: SPECIFICATIONS OF THE SYSTEM

S.NO	INSTRUMENTS USED	SPECIFICATIONS
1.	Conical Tank	Diameter:48 cm Volume :57.90 liters
2.	V-I Converter	
3.	Data Acquisition Card	NI USB DAQ 6211 Voltage type
4.	I-P Converter	Input : 4 to 20 mA Output : 3 to 15 psi
5.	Rotameter	Range:0-1500 Litres per hour
6.	Level Transmitter	Type: DPT with Hart Differential Pressure Range : 0 to 6500mm WC
7.	Control Valve	Input:3 to 15 psi Air to open-Linear type Maximum pressure:35 psi
8.	Reservoir Tank	Volume :114 liters (approx)
9.	Pump	3 phase with variable Frequency Drive(VFD)

III. MATHEMATICAL MODELLING

The area of the conical tank is given by

$A = \pi r^2$

$tan\theta = \frac{r}{h}$

Where,

$r = R*\frac{h}{H}$

therefore,

$tan\theta = \frac{h}{H}$

According to Law of conservation of mass,

Accumulation = Inflow rate - Outflow rate

$A\frac{dh}{dt} = Fin - Fout$

Where, $\frac{dh}{dt}$ = rate of change of height

$Fout = k\sqrt{h}$

K=Discharge coefficient

$\frac{dh}{dt} = F_{in} - K\sqrt{h} * \frac{1}{A}$

Therefore, the mathematical model for single conical tank level for level control is,

$F_{in} - F_{out} = \frac{1}{3}[A\frac{dh}{dt} + \frac{h\left(2\,\pi r2\,\frac{h}{H^2}\right)*dh}{dt}]$

In order to obtain the open loop response in MATLAB SIMULINK the mathematical model for single conical tank is used and simulated. The open loop response of the system is shown in Figure 2.

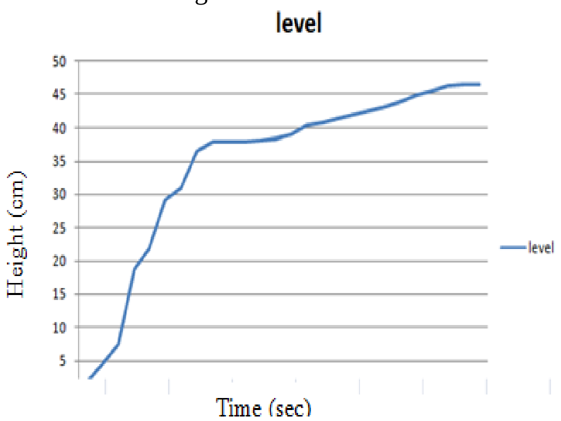

Figure 2: Open loop test response

IV. ADVANCE CONTROLLER DESIGN

Sliding mode control is the variable structure control. Variable control system, including SMC, the control law is deliberately changed during the control process according to some defined rules which depend on the state of the system. In SMC the sliding surface is designed to maintain the system in desired state space. The sliding surface is designed such that the sliding surface drives the non linear plant's state trajectory on to the desired surface by the user in the state space.Once the sliding surface is reached, the SMC maintains the plant's state trajectory on this surface for subsequent time. This in turn eliminates disturbances and reduces sensitivity against unknown parametric perturbations and increases robustness. Due to this increased robustness SMC is recognized as a efficient technique for robust control of uncertain systems. The SMC control law U(t) structure has two important divisions: I) a continuous part $U_c(t)$ and II) a discontinuous part $U_d(t)$.Hence the control law structure is given by,

$U(t) = U_c(t) + U_d(t)$

Where, the continous part of the control law is,

$U_c(t) = f(R(t)\ Y(t))$

The sliding mode controller is designed using a Lyapunov-like function as

$V = \frac{1}{2}S^2$

Where S defines both displacement and velocity.

A sufficient condition for the stability of the system is

$\frac{1}{2}\, d/dt\, S^2 \leq -|S|$

Where S is a positive constant.

The discontinuous control law of SMC is given by

$U_D = \frac{s}{|s| + \square}$

The ε is the chattering suppression factor and it is too be manually adjusted for to eliminate chattering. The error e(t) will be zero when the system lies on sliding surface. The continuous part of control law will be,

$\frac{1}{b} * (a1 - \lambda) * \frac{dH2(t)}{dt} + a_oH_2(t) = U_c(t)$

The procedure for deriving the continuous part of the controller is done from the SMC theory and control procedure. The complete SMC control is represented as,

$\frac{1}{b} * (a1 - \lambda) * \frac{dH2(t)}{dt} + a_oH_2(t) + K * \frac{s}{|s| + \square} = U(t)$

V. RESULTS AND OUTPUT

One of the earlier control strategies used is PID (Proportional-Integral-Derivative. With its three-term functionality which includes treatment to both transient and steady-state responses, PID control offers the simplest and most efficient solution to many real-world control problems.

Hence, PID control is used as a reference to compare with the advanced SMC strategy. The simulation and response of PID control is shown in Figure 3 and Figure 4 respectively.

DOI 10.17148/IJIREEICE.2015.3507

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

IJIREEICE

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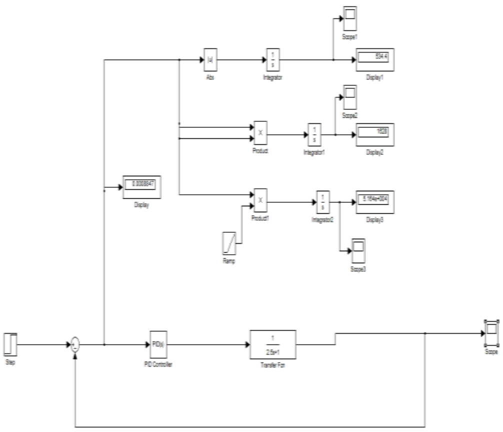

Figure 3:MATLAB simulation for PID

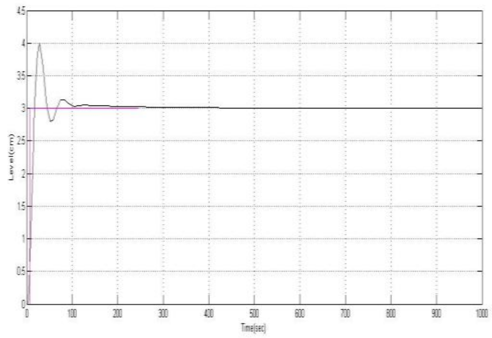

Figure 4: Simulation response of PID

With advances in technology, the science of automatic control has grown to high altitudes and now offers a wide choice of control schemes. And one of them is Sliding Mode Control. The simulation and the response of SMC is shown in Figure 5 and Figure 6 respectively.

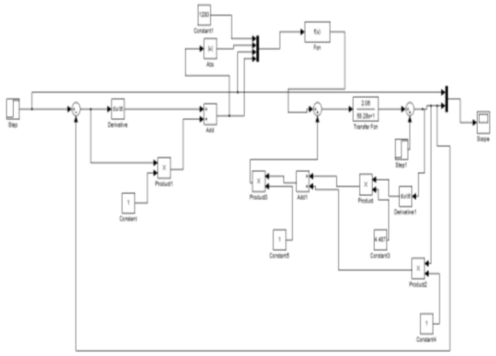

Figure 5: Simulation of SMC

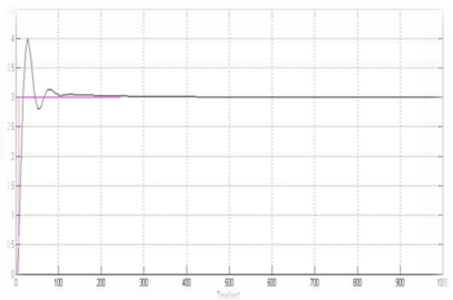

Figure 6: Response of SMC

VI. RESULTS COMPARISION

The PID control and SMC simulation are done and their responses are studied for different parameter changes and their comparision is listed in Table A.

TABLE III: SYSTEM PERFORMANCE ANALYSIS OF PID AND SMC

Parameters	PID controller	Sliding mode controller
Settling time	560	350
Peak overshoot	0.03	0.001
IAE	59.64	6.962
ISE	76.68	14.64
ITAE	2.96e+004	1.13e+004

It can be seen that the performance of SMC is more robust and efficient than the conventional PID control strategy. The performance of the SMC mostly depends on the accuracy of accuracy of designing the sliding surface.

VII. CONCLUSION

The valediction and comparison of sliding mode control with conventional PID control shows that sliding mode control shows better response with no overshoot and less settling time. This project can also be done by using a terminal sliding mode controller .The terminal sliding mode control will improve the attenuation of the disturbance and also increases the performance robustness.

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