PLC Based Adaptive PID Control of Non Linear Liquid Tank System using Online Estimation of Linear Parameters by Difference Equations

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***ABSTRACT*-This paper suggests an idea to design an adaptive PID controller for Non-linear liquid tank System and is implemented in PLC. Online estimation of linear parameters (Time constant and Gain) brings an exact model of the process to take perfect control action. Based on these estimated values, the controller parameters will be well tuned by internal model control. Internal model control is an unremarkably used technique and provides well tuned controller in order to have a good controlling process. PLC with its ability to have both continues control for PID Control and digital control for fault diagnosis which ascertains faults in the system and provides alerts about the status of the entire process.**

Keywords: Estimation, Internal model control, PLC

I. INTRODUCTION

Industrial control systems have galore features as such as non linear, time delay, and time invariant etc, these features causes difficulties in obtaining the exact model. The cone is a well known system, which is having high non linearity, due to the variation of the area with respect to height. This non linearity makes requirement of adaptive PID controller to minimize the error between the desired and actual response. Normally process industries employ PID controller algorithms as it is simple and provides ease of access. The normal PID controller fails to stabilize the system if the process has non linearity and a time delay [1], because non linearity limits the performance of PID [2]. The normal PID controller produces an oscillation when the set point has sudden changes. But non linear (adaptive) PI provides better control action than ZNPI [3]

Intelligent control has some special characteristics which include adaptation, planning and learning like basic features of human intelligence. The adaptive controller plays a vital role in nonlinear process.

Control engineers have used many adaptive algorithms for the PID controller. Among the various controllers, gain scheduling is the most famous algorithm which is used to tune the parameters depending upon the various operating conditions. Combination of adaptive algorithm and learning algorithm afford a variable gain scheduling for different functioning situation [4]. The gain scheduled PID controller is used for modeling and control extremely non linear system like inserting spherical two tank system, conical tank, etc,,. [5]. Fuzzy PID provides better response than PID controller. The fuzzy controller used to regulate the tuning parameters of PID like proportional, integral and derivative gains depends on the process dynamics. The highlight of that paper is the relative rate observer which is used for scaling the parameter regulator [6].

In many of the nonlinear process, obtaining accurate model is an extremely difficult task. Neural network plays a vital role to obtain the mathematical model of the nonlinear process. The online updating neural PID controller is used in nonlinear system to overcome the model problem [7]. Modeling the unknown system is comfortable by estimation of parameters [13]. Internal model control used for online tuning of PID based on estimated values of parameters that provides excellent control action [14], [15]. Internal model control based PID tuning is effective and simple to design in industrial process applications [16]. The pattern based adaptive algorithm is used in tuning the controller parameters of PID and store the parameters concordant to different operating environment implemented on PLC [8].

PLC stands for programmable logical controller which is having the sequential programming. The noise interference is a major problem in manufacturing industries. The computers don't have a capacity to withstand various noises like temperature, vibration etc. So it fails to operate in the correct manner. But PLC's can withstand these conditions. In industrial automation, it is necessary to reduce the human interaction with the process due to automation and security requirements, which can be assured by implementing PLC's [10]. A fuzzy PID controller has been implemented in PLC for controlling the first order plus dead time process [6]. The adaptive algorithm implemented by PLC brings the system to stability and non chafing of noise in industries [9].

II. MATHEMATICAL MODEL

Non-linear liquid tank system exhibits non-linear relationship between its height and Flow rates due their variations in cross-section area. The Mass balance equation of the conical tank states that, the change in volume equal to the difference between the inflow rate and the outflow rate of the tank which has non-linear relationship [11].

$$\frac{dh^3}{dt} = \frac{f_{in} - k_v\sqrt{h}}{\pi\left(\frac{R^2}{3H^2}\right)} \tag{1}$$

III. STRUCTURE OF ADAPTIVE PID

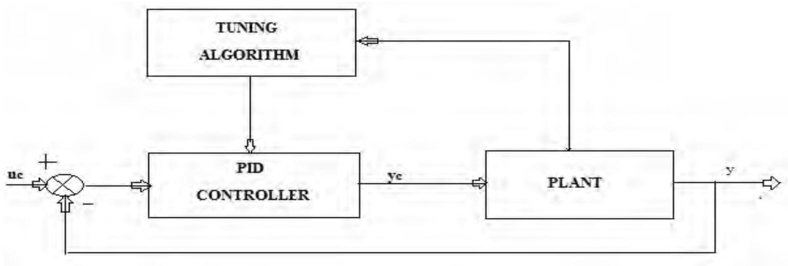

Fig. 1. Structure of adaptive PID

U_c-controller input

Y_c-controller output

The adaptive PID controller, which updates by tuning algorithm on tuning parameters. The PID conroller is the combination of proportional integral and derivative controller. These gains values provide the controller output to take controlling action on the plant. PID is the most beneficial controller, only on the linear system has no changes in process dynamics.

Nonlinear system should have different controlling action depends on the dynamics of the process and is provided by the adaptive PID controller. The tuning algorithm makes PID controller as the adaptive PID controller along changing the parameters of the controller.

IV. ON-LINE ESTIMATION OF LINEAR PARAMETERS

Let us consider the transfer function of the first order system as linear function whose parameters are the gain (K) and time constant (τ) , which have to be estimated

$$y = \frac{K}{\tau S + 1} \tag{2}$$

The Discrete model of the first order system in terms of difference equations is given by equation (6) with sampling time (ts)

$$y(n) = \frac{ku(n) + \frac{y(n-1)\tau}{ts}}{\left(\frac{\tau}{ts} + 1\right)} \tag{3}$$

Lets us consider the discrete model for the past sample data $n \to (n-1)$ Equation (3) can be altered as shown in (4)

$$y(n-1) = \frac{ku(n-1) + \frac{y(n-2)\tau}{ts}}{\left(\frac{\tau}{ts} + 1\right)} \tag{4}$$

On Solving Equation (3) and (4), the linear parameters are estimated in instant as follows,

$$k(n) = \frac{k(n)}{y(n)} \frac{-T(n)(y(n-1) - y(n))}{u(n)} \tag{5}$$

$$T(n) = \frac{u(n)y(n-1) - y(n)u(n-1)}{u(n)\big(y(n-1) - y(n-2)\big) - u(n-1)(y(n-1) - y(n))} \tag{6}$$

Where, K (n)is the gain of the model and T (n) is the normalized time constant. From equation (5) and (6), it is evident that the parameters can be determined by using only five instants of the input and output data. This makes the estimation algorithm simple and can be programmed in a PLC effectively.

V. VALIDATION OF ONLINE ESTIMATION USING LINEAR SYSTEM

The Efficiency of the proposed algorithm was validated by considering a known first order transfer function that gain and time constant values are fixed as follows,

$$\frac{y(s)}{u(s)} = \frac{12.8}{2.5S + 1}$$

Gain (k) =12.8 and Time constant (τ)=2.5

These parameters are constant for entire process. The output and input samples taken from the process for a sampling time period ts.

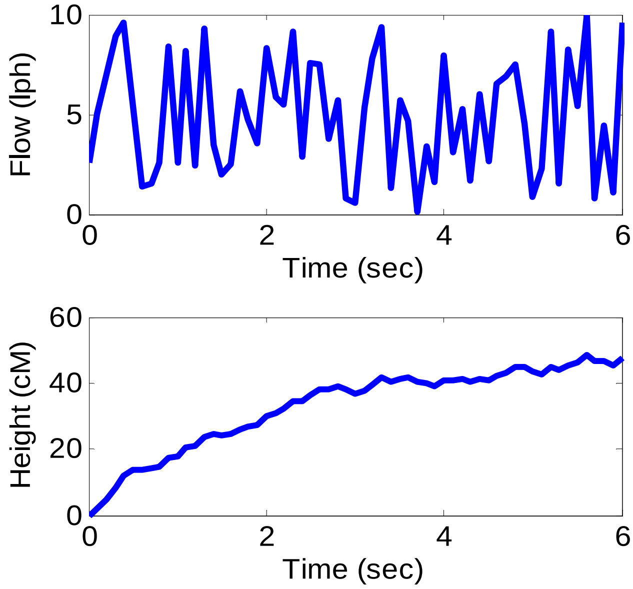

Fig. 2. Randomly input given to the process and output response of the process

From these samples, process gain and time constant can be estimated by the equations (5) and (6)

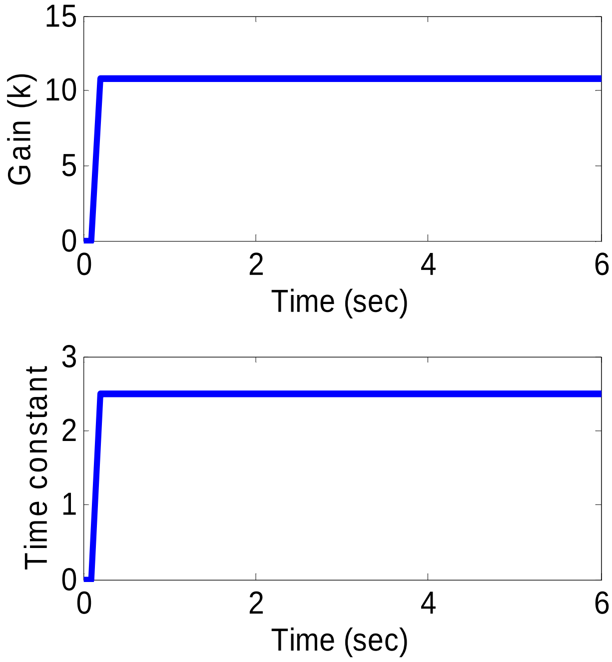

Fig. 3. Estimated values of gain (k) and Time constant (τ)

VI. ON-LINE ESTIMATION OF LINEAR PARAMETERS FOR NON LINEAR SYSTEM

FIN-75lph and Area of conical tank

$$A = 3.14\left(\frac{R*h}{H}\right)^2\left(\frac{1}{3}\right)$$

$$\frac{dh}{dt} = \left(u - kv * sqrt(h)\right)/A$$

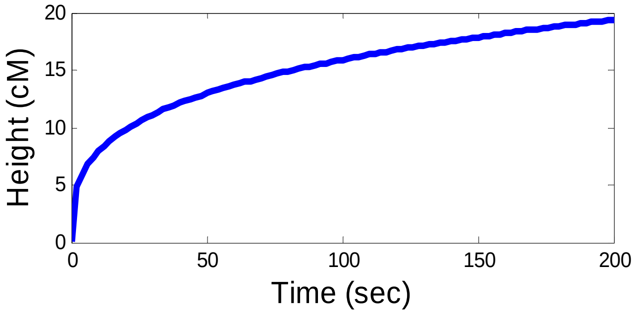

Fig. 4. Output response of conical tank

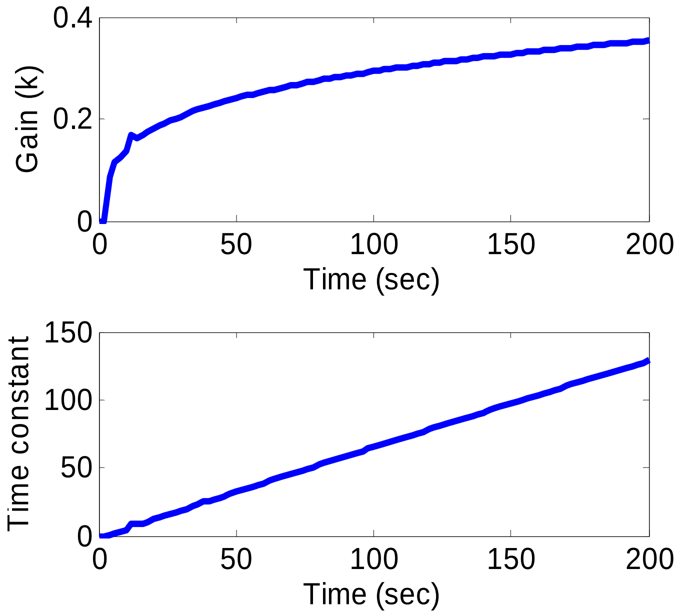

Fig. 5. Estimated values of gain (k) and Time constant (τ)

VII. MODEL VALIDATION FOR NON LINEAR SYSTEM

Model validation is used to ensure correct modeling of the process. Modeling the system is based on estimated values of process which is used to tune PID controller. So is estimating gain and time constant should be correct for perfect controlling action.

$$\frac{y(s)}{u(s)} = \frac{k}{\tau s + 1}$$

$$y(n) = \frac{ku(n) + y(n-1)T(n)}{(T(n) + 1)} \tag{7}$$

The estimated values of gain and time constant substituted in equation (7). The process input is given to this model and compare with response of real time system.

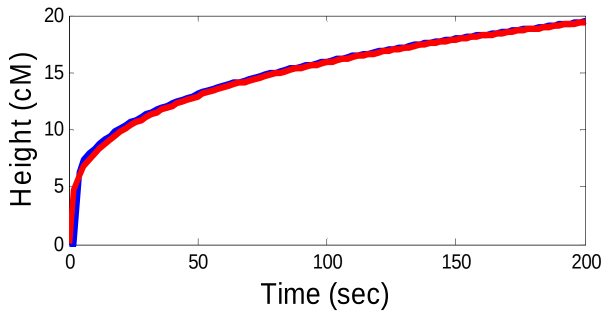

Fig. 6. Comparison of process and model output response

This response shows that the Model is exactly same as a process which indicates estimated values are perfect.

VIII. TUNING ALGORITHM

Internal model control plays critical role for set point tracking and disturbance rejection by tuning of PID controller [12].

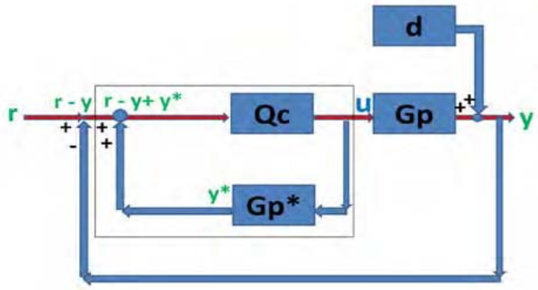

Fig. 7. Structure of IMC

The transfer function of the model is

$$Gp*(S) = \frac{Kp*}{[Tp*S+1]} \quad (8)$$

The equation for PID is

$$Kc\left[e(t) + \frac{1}{Ti}\int e(t) + Td\frac{de(t)}{dt}\right] \quad (9)$$

$$Kc = \frac{Tp}{Kp} * lem\ , Ti = Tp, Td = 0$$

IX. SIMULATION OF ESTMATION AND TUNING BY PLC

The model is developed based on estimated values of gain and time constant. By using these values IMC tuned the PID controller is controlled the process of level maintain in conical tank. All the above algorithms have been implemented by PLC.

X. FAULT DIAGNOSIS

Faults in the system makes controller ineffective, even we have an adaptive algorithm. To overcome this issue the fault diagnosis will be used. Faults can be classified in two types, signal faults and equipment faults. These faults can be diagnosed by logical and sequential diagnosis models that are used to identify the signal and equipment faults in the system [17]. PLC is the easy device to have good fault diagnosis in system.

Setpoint-7Cm

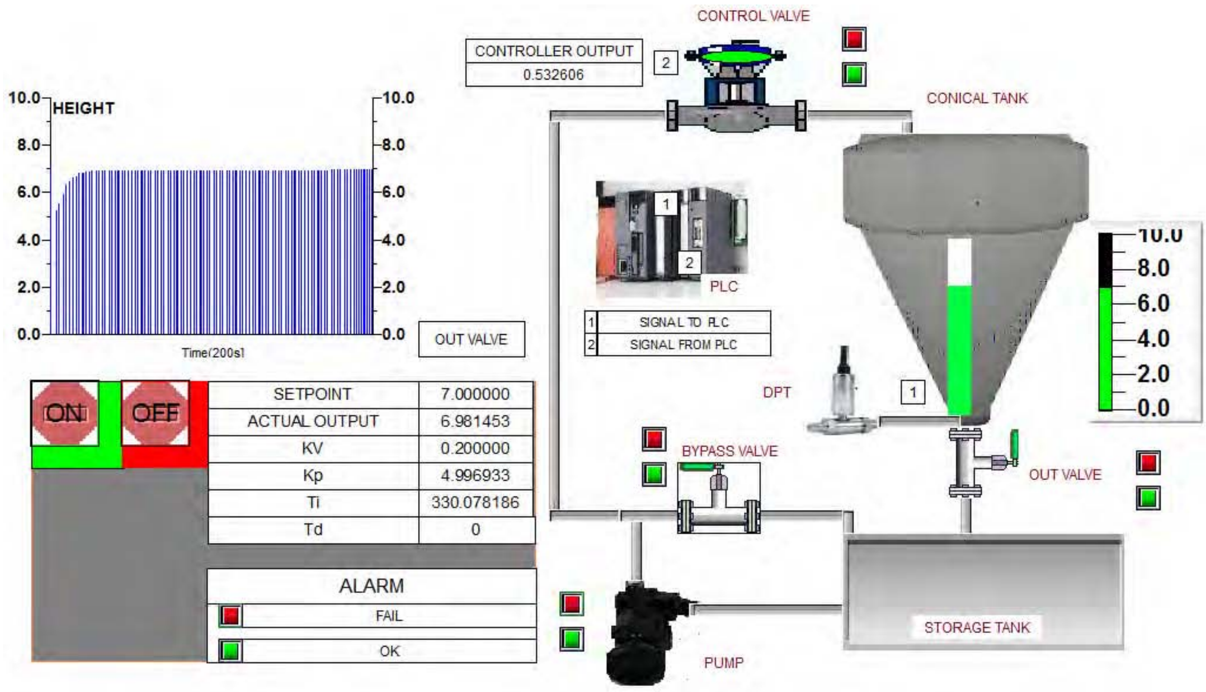

Fig. 8. Level control and fault diagnosis using PLC

	Date	Time	Expression	Message	State
0	11-03-2013	08:56:01	PLC_PRG.BYPASSVALVE	VALVE OPERATES GOOD	INTO
1	11-03-2013	08:55:49	PLC_PRG.OUTVALVE	VALVE OPERATES GOOD	INTO
2	11-03-2013	08:55:58	PLC_PRG.PUMP	PUMP OPERATES GOOD	INTO
3	11-03-2013	08:55:53	PLC_PRG.CONTROLVALVE	VALVE OPERATES GOOD	INTO
4	11-03-2013	08:56:04	PLC_PRG.DPT	DPT OPERATES GOOD	INTO

Fig. 9. Alarm table for fault diagnosis

XI. CONCLUSION

The adaptive PID has been implemented on PLC and is used to control the level of conical tank. The online modeling and tuning leaded non linear to linear system. The estimation of gain and time constant has been used to model the system exactly. By using these estimated values IMC is tuned the PID controller for the required response. Finally correct tuned PID controller controlled the level of the tank according to desired height. So that adaptive PID is the best controller for conical tank.

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