Modeling and Controlling of Conical tank system using adaptive controllers and performance comparison with conventional PID

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ABSTRACT: This paper is about comparison between adaptive PID control and model predictive control in the conical tank process. The level control becomes quite typical due to the nonlinear shape of tank. Many process industries use conical tanks because of its shape contributes to better drainage of solid mixtures, slurries and viscous liquids. So control of conical tank presents a challenging problem due to its non-linearity and constantly changing cross-section.A conventional PID controller is used to control the conical tank system based upon tuning rules available in A.O. Dwyer tuning rules [9]. A single run of the relay feedback experiments carried out to characterize the dynamics including the type of damping behaviour, the ultimate gain, and ultimate frequency. From the knowledge of ultimate gain and ultimate frequency, we can obtain the tuning parameters by using ZN-Closed loop method. Model predictive control (MPC) refers to a class of computer control algorithms that utilize an explicit process model to predict the future response of a plant. MPC designed for conical tank system for multi set point tracking to achieve the desired performance.

Keywords:- conical tank; open loop system; Relay feedback test; PID control; MPC(model predictive control); MATLAB/SIMULINK

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I. INTRODUCTION

The control of liquid level [7] in tank and flow in the tank is a basic problem in process industries. The process industries require the liquids to be pumped, stored in tanks and then pumped to another tank. Many times the liquid will be processed by chemical or mixing treatment in the tanks, but always the level of the fluid in the tanks must be controlled. Controlling of liquid level is an important and common task in process industries ,in this level process the tank is conical 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 a tank and the manipulated variable is the inflow to the tank. Conical tanks find wide applications in process industries, namely hydrometallurgical industries, food process industries, concrete mixing industries and wastewater treatment industries.

A proportional-integral-derivative controller (PID) Controller) [4] is a common feedback loop component used for control system. In this paper a PID controller is implemented to track the set point and also to reject the disturbance occurs in the process. Relay feedback test is conducted to carry out the tuning parameters of PID controller to satisfy the servo and regulatory responses.

Model predictive control (MPC) refers to a class of computer control algorithms that utilize an explicit process model to predict the future response of a plant.Model predictive control is a form of control in which the current control action is obtained by solving, at each sampling instant, a finite horizon open loop optimal control problem, using the current state of the plant as the initial state, the optimization yields an optimal control sequence and first control in this sequence is applied to the plant.

II. CONICAL TANK LEVEL SYSTEM

In this level process the tank is conical 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 a tank and the manipulated variable is the inflow to the tank. The schematic diagram of the
system is shown in the following Fig (1).

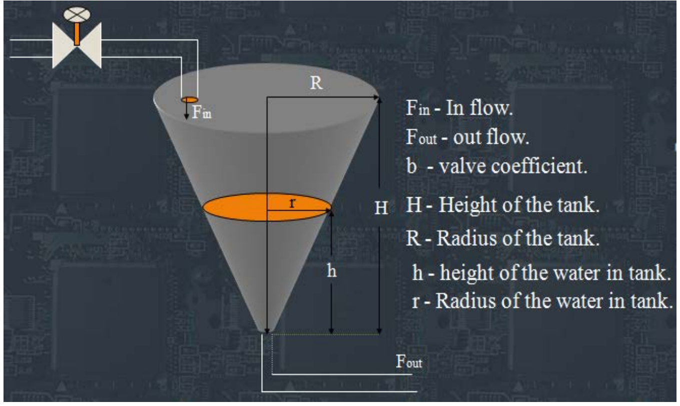

Fig.1 Schematic diagram of conical level system

A. *Mathematical model:*

$$F_{in} - F_{out} = \frac{A(h_1)dh_1}{dt} \quad (1)$$

$$\tan\theta = R/H \quad (2)$$

At any level $(h_1) \tan\theta = r/h_1$ (3)

Cross sectional area of the tank at any level (h_1)

$$A(h_1) = \prod r^2 \quad (4)$$

$$A(h_1) = \pi R^2 h_1{}^2/H^2 (5)$$

$$F_{out} = b\sqrt{h_1} \quad (6)$$

$$F_{in} - b\sqrt{h_1} = \frac{A(h_1)dh_1}{dt} \quad (7)$$

$$\frac{dh_1}{dt} = \frac{F_{in} - b\sqrt{h_1}}{\pi R^2 h_1{}^2/H^2} \quad (8)$$

By integrating Eqn.(8), the mathematical model can be written as follows,

$$h_1 = \int (F_{in} - b\sqrt{h_1}) * \frac{1}{\pi} * \frac{H^2}{h^2} * \frac{1}{R^2} \quad (9)$$

The conical tank with gravity flow introduces a severe non linearity from the extreme changes in area. The dependence of discharge flow on the square root of the static head creates another non linearity and negative feedback. The process no longer has a true integrating response. The equations are approximation because the head term (h) was not isolated. Since the radius(r) of the cross-sectional area at the surface is proportional to the height of the level as depicted in fig.1, it is expected that the decrease in process time constant is much larger than the decrease in process gain with a decrease in level.

B. *Transfer function*:

The transfer function is obtained from the proceedings of "Design of Controllers based on MPC for a Conical Tank System" [6]. The transfer function is given by

$$G(S) = \frac{12.87\, e^{-0.1s}}{46.9s + 1} \quad (10)$$

III. CONTROL METHODS

1. *PID CONTROLLER:*

When the characteristics of a plant are not suitable, they can be changed by adding a compensator [3] in the control system. One of the simple and useful compensators feedback control design is described in this section. In this paper, 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.

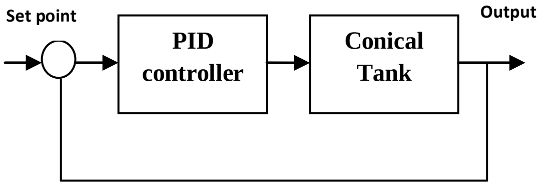

Fig. 2 Block diagram of closed loop system

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

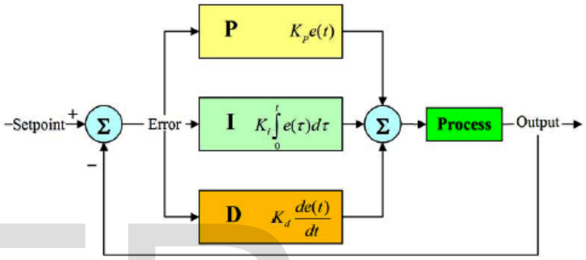

Fig. 3 Block diagram of PID controller

Three parameters K_d ,K_p and $K_i$must be adjusted in the PID controller. In guaranteeing stability and performance and shaping the closed-loop response, it is important to select a suitable compensator.

A. *Proportional gain Kp:*

Large proportional control can increase response, speed and reduce the steady state error, but will lead to oscillation of the system.

B. Integral gain K_I:

Integral control is favorable for diminishing the steady state error but it will lengthen the transient response. This paper attempts to design optimal values for controller parameters. Then it obtained the value of PID gains by Ziegler and Nichols method. Ziegler and Nichols provided a technique for selecting the PID gains that works for a large class of industrial systems.

2. RELAY FEEDBACK TEST:

The Astrom and Hagglund relay feedback test is based on the observation that, when the output lags behind the input

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by π radians, the closed-loop system can oscillate with a period of *P*u. The block diagram of relay feedback test is shown in figure (4). The output response of relay feedback test is shown in fig (5). From the response we can find the parameters are ultimate gain and ultimate period by using equations (12) & (13).

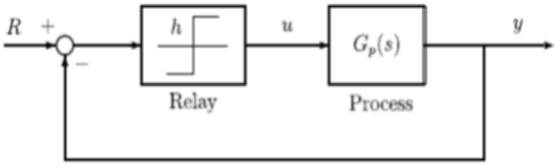

Fig. 4 Block diagram of Relay feedback test.

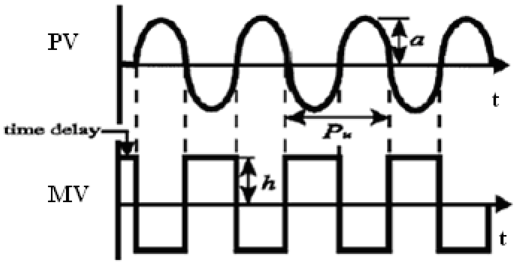

Fig.5: Output response of relay feedback test.

A relay of magnitude *h* is inserted in the feedback loop. Initially, the input *u*(*t*) is increased by *h*. Once the output *y*(*t*) starts increasing after a time delay (*D*), the relay switches to the opposite direction, *u*(*t*) -*h*. Because there is a phase lag of $-\pi$, a limit cycle of amplitude *a* is generated, as shown in Figure 1. The period of the limit cycle is the ultimate period, *P*u. The approximate ultimate gain, *K*u, and the ultimate frequency, w_u are

$$K_u = \frac{4h}{\pi a} \qquad (11)$$

$$W_u = \frac{2\pi}{P_u} \qquad (12)$$

3. *MODEL PREDICTIVE CONTROLLER:*

The model predictive control[8] problem is formulated as solving on-line a finite horizon open-loop optimal control problem subject to system dynamics and constraints involving states and controls. Figure (6) shows the basic principle of model predictive control. Based on measurements obtained at time *t*, the controller predicts the future dynamic behavior of the system over a prediction horizon *Tp* and determines (over a control horizon) the input such that a predetermined open-loop performance object function is optimized.

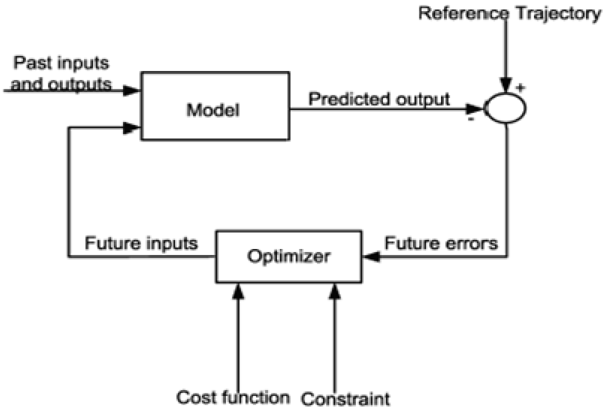

Fig6: Block diagram of the MPC controller.

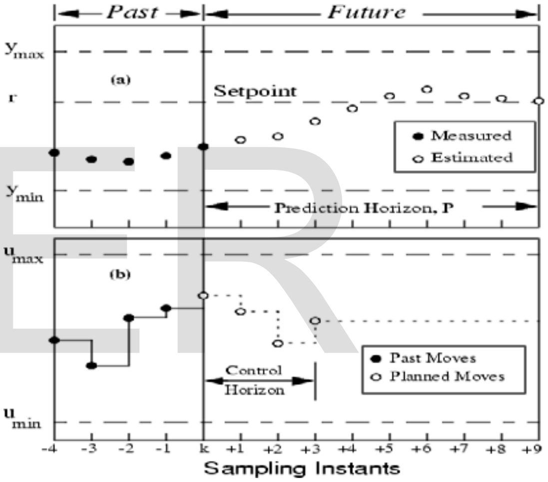

Fig7: Performance of MPC controller

Optimization Function:

A mathematical description of the cost function used by the controller to optimize control moves over the control horizon is given, values of set points, measured disturbances, and constraints are

specified over a finite horizon of future sampling instants, k+1, k+2, ...,k+P, where P is the prediction horizon and the controller computes M moves uk, uk+1, ... uk+M-1, where M is the control horizon as shown in fig-7. For Conical Tank system consider the predictive horizon P = 20 and control horizon M = 3, to track the servo and regulatory response under multi set point tracking system. The cost function/optimization equation to reduce the error is shown in below.

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$$\min_{\Delta u(k|k),\,\ldots,\,\Delta u(m-1+k|k),\,\varepsilon} \left\{ \sum_{i=0}^{p-1} \left(\sum_{j=1}^{n_y} \left| w^{y}_{i+1,j}\left(y_j(k+i+1|k) - r_j(k+i+1)\right) \right|^2 + \sum_{j=1}^{n_u} \left| w^{\Delta u}_{i,j} \Delta u_j(k+i|k) \right|^2 + \sum_{j=1}^{n_u} \left| w^{u}_{i,j}\left(u_j(k+i|k) - u_{j\text{target}}(k+i)\right) \right|^2 \right) + \rho_\varepsilon \varepsilon^2 \right\}$$

IV. SIMULATION RESULTS

A. *Simulation Method:*

The mathematical model of conical tank is obtained using first principle equation and is implemented by using MATLAB/Simulink. The Simulink model of conical tank system is shown in fig.8. The system behavioris analyzed by using the step response model of conical tank system.

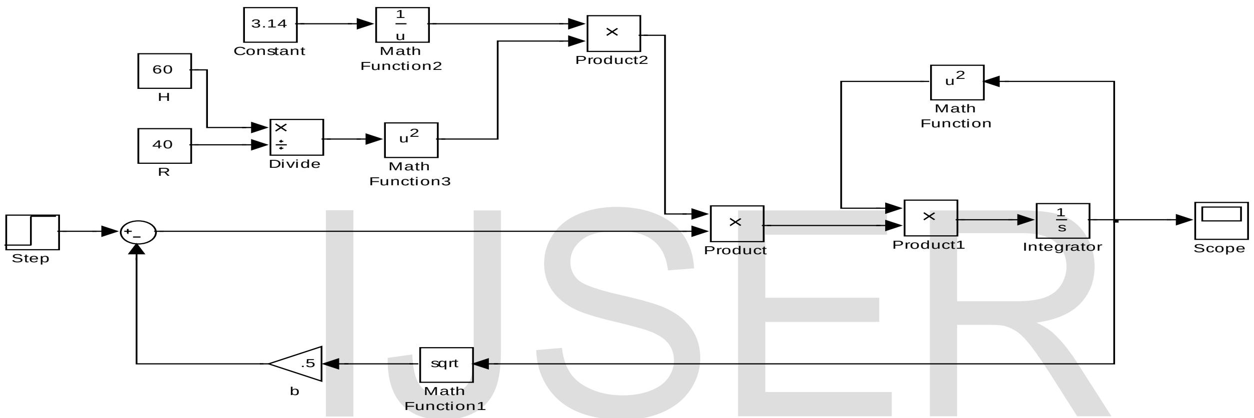

Fig.8: Open loop response of Conical Tank System

B. Tuning rules:

C. Table 1: Tuning rules for PID Controller

Tuning rules	Kc	Ti	Td
Z-N Closed loop method	$0.6K_U$	$0.5P_u$	$0.125P_u$
Chienet *al.* regulator. *Model: Method 2*	$0.95T_M/(K_m\tau_m)$	$2.38\tau_m$	$0.42\tau_m$
Chienet *al.* servo. *Model:*	$0.6T_M/(K_m\tau_m)$	T_M	$0.5\tau_m$
Chienet *al.* servo. *Model:*	$0.95T_M/(K_M\tau_m)$	$1.36T_M$	$0.47\tau_m$

The tuning rules are obtained from the [9] Handbook of PI and PID controller tuning rules by Aidan O'Dwyer are listed in Table (1). The tuning parameters of PID controller is calculated by using the tuning rules provided in table (1).

D. SIMULATION RESULTS:

The open loop response of the first principle model is shown in fig-9. The validation response of conical tank system with the first principle method and linearised

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transfer function response is shown in fig.10. From the fig-10 we can analyse that the both responses are same for same change in step input to the process. The responses related to different tuning rules for tracking the servo response is shown in fig (11) and PID controller response is shown in fig (12). From the fig (11) we analyse that the Zeigler-Nicholos tuning rules provides ocillatory response to track the set point change in process. Chien servo method-2 provides less oscillatory response and fast settling time compared to all other tuning rules.

The performance index of ISE, IAE, ITAE and ITSE for various tuning rules is shown in Table-2. From the table -2 we can analyze that Chien at el. Regulator method provides less ISE, IAE ITAE values compared to other tuning parameters.

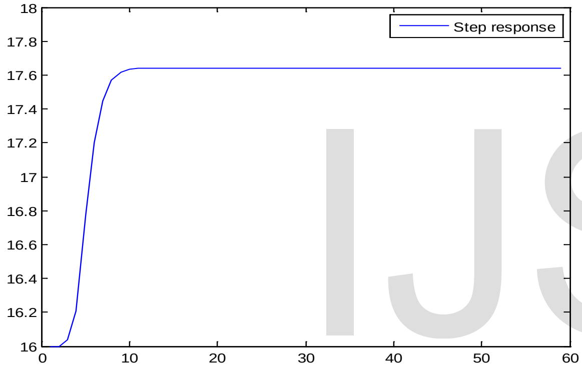

Fig.9: Step response of Conical Tank system

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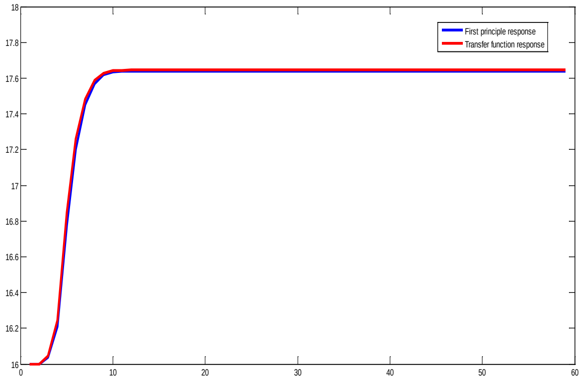

Fig 10: Validation of the system with first principle model.

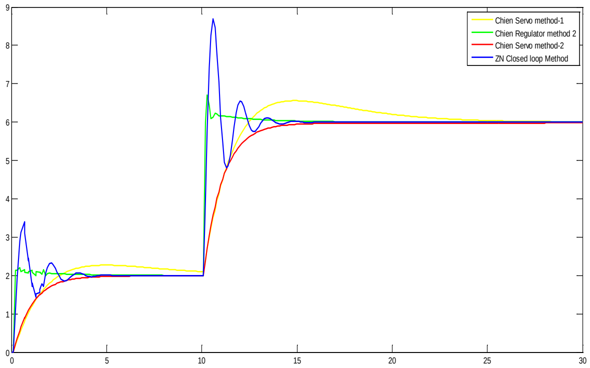

Fig11: Output response of Conical Tank system for multi set point tracking by using the different tuning rules.

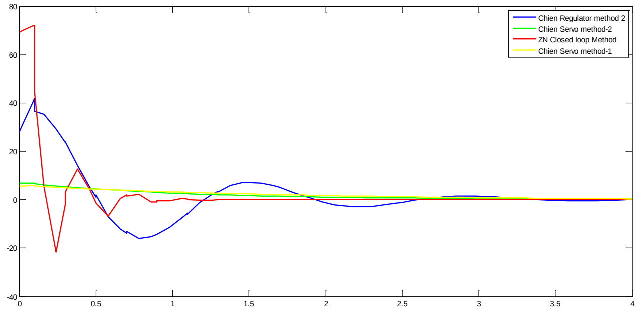

Fig12: PID controller response for Conical Tank system by using the different tuning rules.

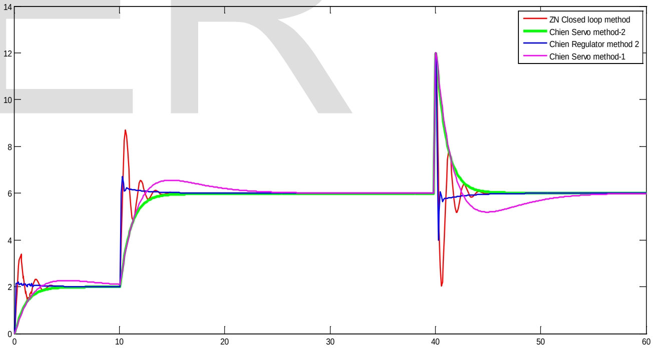

Fig 13: Tracking of Servo and regulatory response for Conical Tank system

E. MODEL PREDICTIVE CONTROLLER:

The implementation of Model predictive control for conical tank process to track the multi changes in set point and also the change in load disturbance. For implementing the MPC we consider Pridiction Horizon P=20, Control Horizon M=3 .The simulink diagram for implementation of MPC controller for Conical tank process in shown in fig-14. The multi input tracking of conical tank system is achevied by using MPC controller with out any oscillations and with in short period of time, is shown in fig-15.

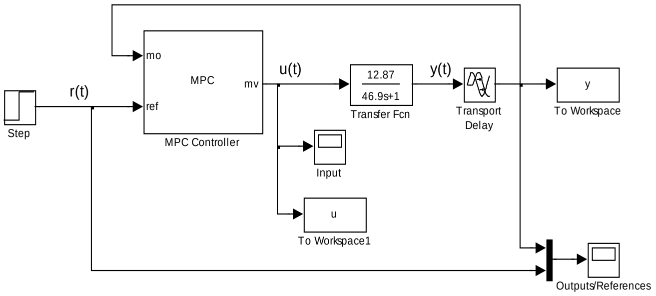

Fig.14: Simulink diagram of MPC with conical tank system.

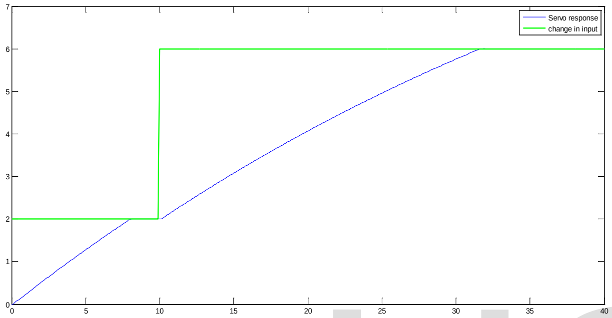

Fig 15: Multi set point tracking using MPC for conical tank system.

Table 2: Analysis of Performance index for different tuning rules

Tuning method	ISE	IAE	ITSE	ITAE
Z-N Closed loop method	**7.388**	**5.399**	**64.66**	**52.47**
Chien*et al.* regulator. *Model: Method 2*	**2.914**	**1.955**	**24.32**	**178.74**
Chien*et al.* servo. *Model: Method 2*	**13.55**	**10.84**	**123**	**112.8**
Chien*et al.* servo. *Model: Method 2*	**12.08**	**7.355**	**103.2**	**68.04**

V. CONCLUSION

The conical tank system is identified as a non-linear system. The model of conical tank system is implemented with the help of first principle differential equation. MATLAB ODE45 solver/Simulink is used to solve the differential equation. The results are validated by using the transfer function model and ODE response. The conventional PID controller is implemented to track the multi set point changes in level of the conical tank process by using different tuning rules. The relay feedback test conducted to the process to identify the tuning parameters of PID structure. The MPC Controller also implemented to track the servo response and regulatory response. The performance index of different tuning rules are also obtained. The simulation results proven that the MPC control method is an easy-tuning and more effective way to enhance stability of time domain performance of the conical tank system.

VI. FUTURE WORK

The controller can be implemented by using constraints on Model Predictive Control to track the servo response and regulatory response. The advanced Controllers like Self tuning regulator with process parameter estimation, Model Reference Adaptive Controller etc can be implemented for conical tank system for satisfactory desired performance.

VII. REFERENCES

[1] J.G.Ziegler and N.B.Nichols, Rochester.N.Y, "Optimum Settings forAutomatic Controllers," Trans.ASME,64,1942,pp.759-765.

[2]S.Nithya, N.Sivakumaran, T.K.Radhakrishnan, N.Anantharaman "SoftComputing based controllers implementation for non-linear process inreal time", WCECS 2010, VOL II.

[3] V.R.Ravi, T.Thyagarajan, "A Decentralized PID controller forinteracting non-linear systems."ICETECT 2011 pp 297-302.

[4] S.Nithya, N.Sivakumaran, T.K.Radhakrishnan, N.Anantharaman,"Control of nonlinear process usingsoft Computing" IUP 2010

[5] S.Nithya, Abhay Singh Gour, N.Sivakumaran, T.K.Radhakrishnan,T.Balasubramanian, N.Anantharaman "Design of Intelligent controllersfor nonlinear processes",AJAPS,2008.pp 33-45.

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[6] SukanyaR.warier, Sivanandamvenkatesh "Design of controller based on MPC for a conical tank system",(ICAESM-2012).

[7] S.Nithya, K.VijayarekhaN.Sivakumaran, T.Balasubramanian,N.Anantharaman, "Controllers implementation based on soft computingfor Nonlinear process," IEEE 2008 pp 126-131.

[8] V.R.Ravi,T.Thyagarajan, "Application of adaptive control technique tointeracting Non Linear Systems", IEEE 2011 pp 386-392.

[9]Aidan o'Dwyer, "Hand book of PI and PID controller tuning rules",3rd edition page no.78.

[10] Clarke, D.W. "Application of Generalized Predictive Control to Industrial Processes," IEEE Cont. Sys. Mag., 49-55, April (1988).

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