ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

MPC Based Fuzzy Logic Controller for Non Linear Process

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ABSTRACT: Non linear process is the immense challenge in process control and it cannot be effectively controlled by means of conventional linear P+I+D controller. Hence an attempt is made in this paper as Model Predictive Control algorithm based fuzzy logic controller design for conical tank level control. For each stable operating point, a first order process model was identified using process reaction curve method. The real time implementation is done in simulink using MATLAB. The experimental results shows that proposed control scheme have good set point tracking and disturbance rejection capability**.**

KEYWORDS*:* MPC;PID;Fuzzy;Conical tank;MATLAB

I. INTRODUCTION

In most of the process industries controlling of level, flow, temperature and pressure is a challenging one. Based on the plant dynamics, they may be classified as linear and non-linear processes. In level control process, the tank systems like cylindrical, cubical are a linear one, but that type of tanks does not provides a complete drainage. For complete drainage of fluids, a conical bottomed cylindrical tank is used in some of the process industries, where its nonlinearity might be at the bottom only. The drainage efficiency can be improved further if the tank is fully conical. But continuous variation in the tank system makes it highly non-linear and hence the liquid level control in such systems is difficult. A conical shaped tank system are mainly used in Colloidal mills, Leaching extractions in pharmaceutical and chemical industries, food processing industries, Petroleum industries, Molasses, Liquid feed and Liquid fertilizer storage, Chemical holding & mix tank, Biodiesel processing and reactor tank. To avoid settlement and sludge in Storage and holding tanks, the conical tanks are used.

II. PROPOSED WORK

A. EXPERIMENTAL SETUP

The level process station was used to conduct the experiments and collect the data. The computer acts as a controller .It consists of the software used to control the level process station. The setup consists of a process tank, reservoir tank, control valve, I to P converter, level sensor and pneumatic signals from the compressor. When the set up is Switched on, level sensor senses the actual level values initially then signal is converted to current signal in the range 4 to 20mA.This signal is then given computer through data acquisition cord. Based on the values entered in the controller Settings and the set point the computer will take control action the signal sent by the computer is taken to the station again through the cord. This signal is then converted to pressure signal using I to P converter. Then the pressure signal acts on a control value which controls the flow of water in to the tank there by controlling the level.

10.15662/ijareeie.2015.0404035

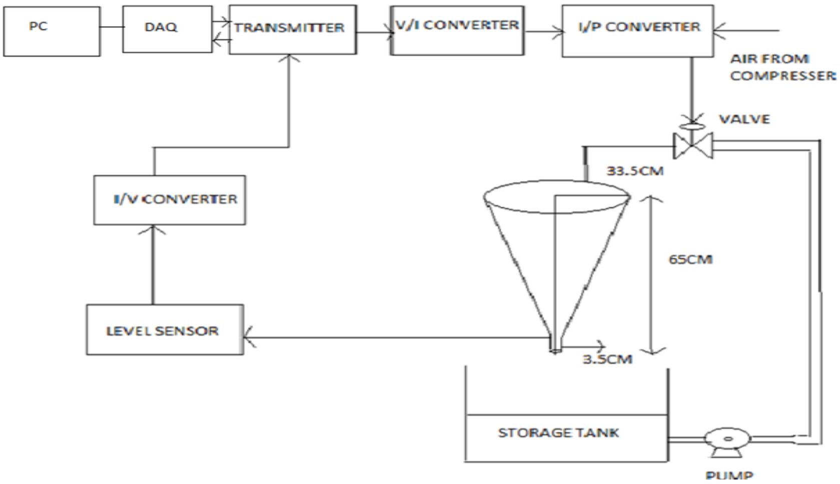

Figure 1: Level Control of Conical Tank System

Figure 1 shows the experimental setup of conical tank level control process

B. DESCRIPTION OF THE CONICAL – TANK LEVEL PROCESS

The tank is made up of stainless steel body and is mounted over a stand vertically. Water enters the tank from the top and leaves the bottom to the storage tank. The System specifications of the tank are as follows,

TABLE I
SPECIFICATIONS OF PROPOSED SYSTEM

EQUIPMENTS	DETAILS
Conical tank	Stainless steel body, height– 65 cm, Top diameter–33.5 cm Bottom diameter – 3.5 cm
Differential Pressure Level Transmitter	Differential Pressure Level Transmitter
Pump	Centrifugal 0.5 HP
Control Valve	Size ¼ Pneumatic actuated Type: Air to open, Input 3-15PSI
Rota meter	Range 0-460 LPH

C. MATHEMATICAL MODELING OF PROCESS

A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical model is termed as mathematical modeling. Generally modeling of linear systems involves direct derivations whereas non- linear systems require certain approximations to arrive at the solution.

Types of Non-linear Approximations:

- Taylor Series Approximation
- Optimal Approximation
- Global Approximation
- Jacobian Method

Of these methods, Taylor’s series method is simple and accurate over certain range near the steady state point.

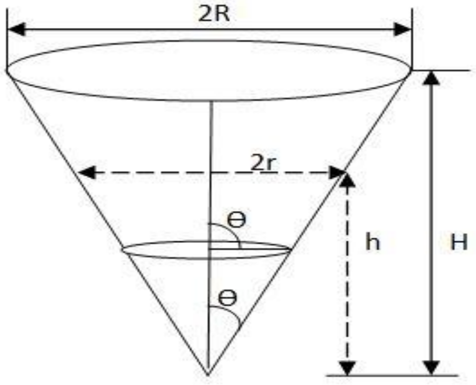

Figure 2: Mathematical Modeling

Where,

R = Top radius of the tank
H = Total height of the tank
r = Radius at the liquid level (h)
h = Level of the liquid (Variable)

tanƏ= r/h and also tanƏ=R/H (1)

Therefore, $r/h=R/H$ (2)

$R =(R*h)/H$ (3)

Area $A=\pi r^2$ (4)

$dA/dt=d\{\pi((R*h)/H)^2\}/dt$ (5)

$=\pi(R/H)^2 *2h\, dh/dt$ (6)

Volume $V=1/3 *\pi r^2 h$ (7)

$=1/3*Ah$ (8)

$dV/dt=1/3*\{A\, dh/dt+hdA/dt\}$ (9)

$=1/3 *dh/dt\{A+2\pi(R/H)^2*h^2\}$ (10)

By Newton’s law

$F_{in}-F_{out}=1/3 *dh/dt\{A+2\pi(R/H)^2*h^2\}$ (11)

Output flow rate,

$F_{out}= K\sqrt{h}$ (12)

$F_{in}-K\sqrt{h} =1/3 *dh/dt\{A+2\pi(R/H)^2*h^2\}$ (13)

$dh/dt = \{3(F_{in}-K\sqrt{h})\}/\{ A+2\pi(R/H)^2*h^2\}$ (14)

$dh/dt = \{3(F_{in}-K\sqrt{h})\}/\{ 3\pi(R/H)^2*h^2\}$ (15)

$= \{(F_{in}-K\sqrt{h})\}/\{ \pi(R/H)^2*h^2\}$ (16)

$\alpha = 1/ \pi(R/H)^2$ (17)

$\beta = K\alpha$ (18)

$dh/dt= \alpha F_{in}\, h^{-2}-\beta h^{-3/2}$ (19)

By Taylor's series:

$F(h,F_i) = f(h_s ,F_{is}) + (\partial f/\partial h)_{(hs,Fis)} (h-h_s) + (\partial f/\partial F_i)_{(hs-fis)}F(f_i-F_{is})$ (20)

$F(h,F_i) = f(h_s ,F_{is}) - 2F_{is}\, h_s^{-3}(h-h_s) + h_s^{-2}(F-F_{is})$ (21)

$h^{-3/2}= h_s^{-3/2} - (3/2)h_s^{-5/2}(h-h_s)$ (22)

$dh/dt = \alpha[f(h_s ,F_{is}) - 2F_{is}\, h_s^{-3}(h-h_s) + h_s^{-2}(F-F_{is})] - \beta[h_s^{-3/2}- (3/2)h_s^{-5/2}(h-h_s)]$ (23)

At steady state,

$dh_s/dt = \alpha F_{is}h_s^{-2}-\beta h_s^{-3/2}= 0$ (24)

$d(h-h_s)/dt= -2\alpha F_{is}h_s^{-3}(h-h_s) + \alpha h_s^{-2}(F-F_{is})] + 3/2\beta h_s^{-5/2}(h-h_s)$ (25)

$dy/dt = -2\alpha F_{is}h_s^{-3}Y + \alpha h_s^{-2}U + (3/2)\beta h_s^{-5/2}Y$ (26)

$dy/dt = -2\beta h_s^{-3/2}h_s^{-1}\, y + \alpha h_s^{-2}U + (3/2)\beta h_s^{-5/2}Y$

$= -(1/2)\, \beta h_s^{-5/2}y + \alpha h_s^{-2}U$ (27)

$(2/\beta)\, h_s^{5/2}(dy/dt) = -y + \alpha hs^{-2}U$

$\tau(dy/dt) + y = (2\alpha/\beta)\, h_s^{1/2}U$ (28)

$\tau(dy/dt) + y = CU$ (29)

Taking Laplace Transform,

$Y(s)/U(s) = C/[\tau s+1]$ (30)

Where,

$C = (2\alpha/\beta)\, h_s^{1/2}$ → Steady State Gain.

$\tau = (2/\beta)\, h_s^{5/2}$ → Time Constant.

D. RESPONSE OF OPEN LOOP TEST:

The response of the open loop test as described in chapter 6.1 is given below. It shows that the steady state gain is 12mA and time constant 7.62 sec with input step change of 100LPH.

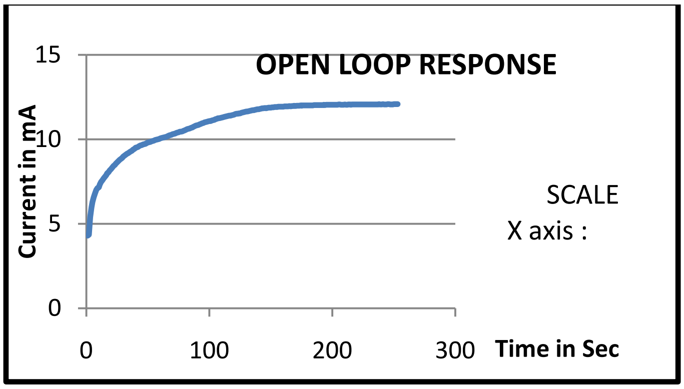

Figure 3: Openloop Response Cruve

The obtained response from open loop test which represents First order transfer function with zero dead time.

$$G(S) = \frac{Kpe^{-\tau_d\,(s)}}{\tau s+1} \quad (31)$$

E. Linearization

The process steady state input output characteristics thus obtained shows the non-linear behavior as the area varies in a non-linear fashion with the process variable height (h).To obtain a linear model process steady state input –output characteristics curve is divided into five different linear regions as shown in the fig 4

TABLE II
MODEL PARAMETERS

Region	Height (cm)	kp	Time Constant (sec)	Transfer Function Model
1	70	0.718	144	0.92/144s+1
2	100	0.855	212	2.999/212s+1

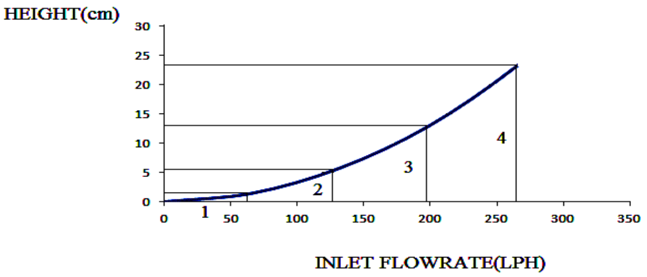

Figure 4: Piecewise Linearization Curve

III. MPC BASED FUZZY CONTROLLER

MPC is a form of control in which the current control action is obtained by solving on-line. 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 the first control in this sequence is applied to the plant.

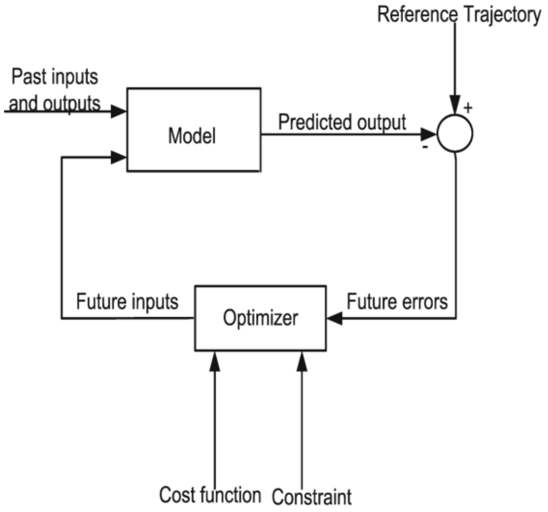

Figure 5: Structure of MPC

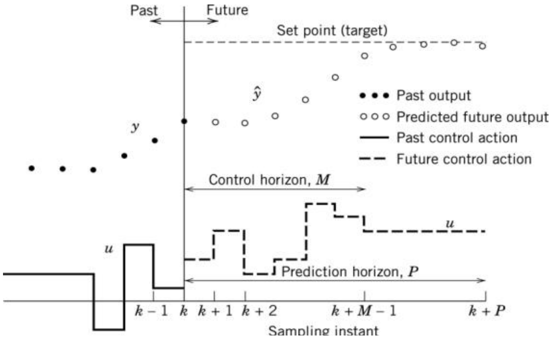

Figure 6: Concept of MPC

$$y(k+1) = y_0 + \sum_{i=1}^{N-1} S_i \Delta u(k-i+1) + S_N u(k-N+1) \quad (32)$$

Equation 32 shows that step response model where S_i = the i-th step response coefficient N = an integer (the *model horizon)* y_0 = initial value at k=0 Figure 6 shows that Model Predictive Control (MPC) – regulatory controls that use an explicit dynamic model of the response of process variables to changes in manipulated variables to calculate control "moves".

E	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NS	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PS	PB
PB	Z	PS	PB	PB	PB

Figure 7:Fuzzy Rules

IV SIMULATION AND RESULTS

The simulation result of MPC based Fuzzy with various operating points was obtained using MATLAB environment. The performance of the proposed controller is compared with existing conventional controller.

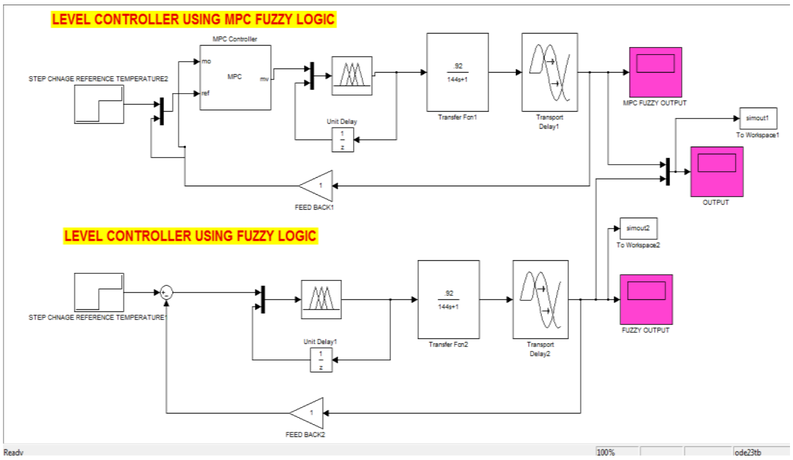

Figure 8: MATLAB Simulink Model.

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This structures for compensate the disturbance model uncertainty. The procedure is focused on set point responses. But a good set point response denotes good disturbance rejection particularly for the disturbance occurs at the process input. The modified of the design procedure is developed to improve input disturbance rejection.

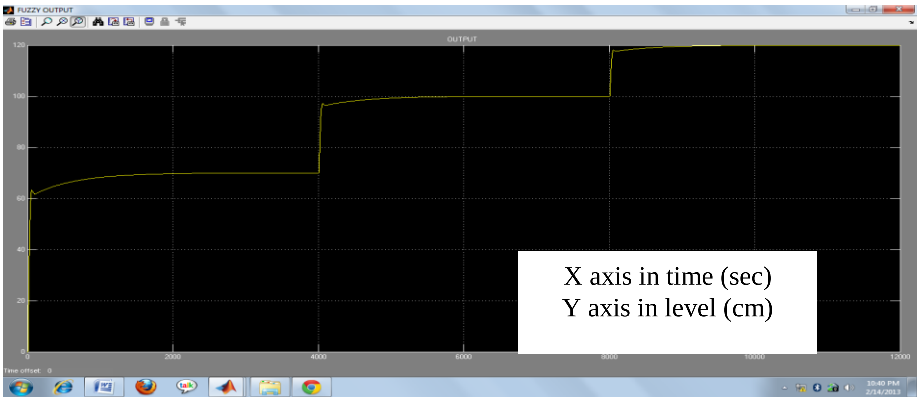

Figure 9: Simulation for Fuzzy output

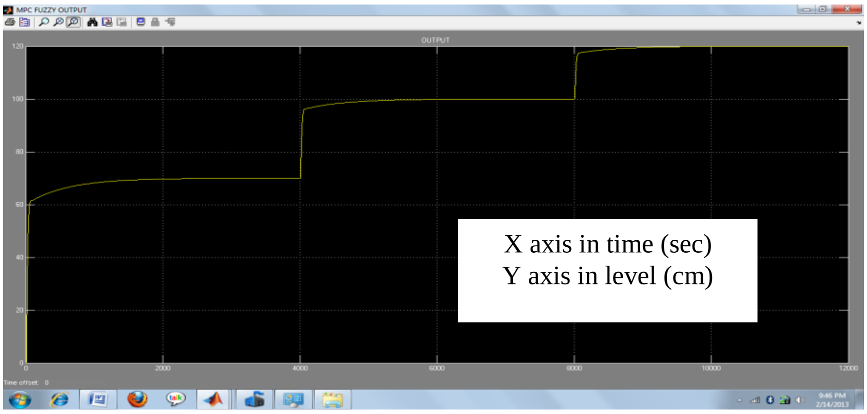

Figure 10: Simulation for MPC based Fuzzy output

Figure 9,10 shows that the MPC based fuzzy logic controller having good set point tracking capability when compared to Fuzzy logic controller also the time domain specifications has to be normalized.

TABLE III
COMPARISION OF FUZZY AND MPC BASED FUZZY

Set point (Step input)	Controller	Rise time (secs)	Settling time (sec)
70	Fuzzy	200	1100
	MPC based Fuzzy	100	990
100	Fuzzy	420	4200
	MPC based Fuzzy	310	3100

V. CONCLUSION

For practical applications or an actual process in industries MPC based fuzzy controller algorithm is simple and robust to handle the model inaccuracies and hence using MPC-Fuzzy tuning method a clear trade-off between closed-loop performance and robustness to model inaccuracies is achieved with tuning parameter. It also provides a good solution to the process with significant time delays which is actually the case with working in real time environment. As far as the tuning of the controller is concerned we have optimum control and prediction vector which compromises the effects of discrepancies entering into the system to achieve the best performance. Thus, what we mean by the best control horizon that gives the best MPC performance for the optimum Prediction value. Also the standard MPC based Fuzzy controller results in good set point response performances. The simulation results shows the MPC based Fuzzy controller have minimum settling time and rise time in order to reach steady state value when compare to conventional controller.

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