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Comparative Performance Analysis of Level Process with Diverse Techniques

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ABSTRACT: This paper deals with the proposal of the controller for a Level process. The level process is controlled by PID controller using different control methods such as IMC, MPC and then the result of mentioned control algorithms has been compared in terms of time domain specifications like settling time (t_s) , rise time (t_r), maximum overshoot (M_p) and performance indices like ISE, IAE,MSE. The objective of this paper is to analyse the MPC strategy and contrast the control method with conventional strategy of control in maintaining a water level in a single tank system. The conventional controller, IMC and MPC has been compared in which MPC controller gives a enhanced system performance in terms of settling time (t_s) , rise time (t_r), maximum overshoot (M_p) and hence their performance indices ISE, IAE,MSE are analysed.

KEYWORDS: PID control, IMC, MPC, performance factors.

I INTRODUCTION

In process industries, the control of liquid level is a basic problem especially in industries like petro-chemical industries, paper mixing process or mixing treatment in the tanks in paper industries. It is essential for a control systems engineer to understand the problem and to control the level. Draining liquid out of silo and pumping oil into the storage tanks are important processes in petrochemical industries which mainly rely on level control for safe and efficient operation. The quantity of the product of mixture depends on the level of the reactants in the mixing tank. Chemical process industries and food processing industries employs mixing reactant process.

Process industries now follow computer aided control for field and simulation based analysis. and hence, MATLAB is used in this work to analyse the best mode of control for a single tank level process and hence the performance determining factors.

In the liquid level control system, the manipulated variables of the liquid level are controlled. In the industrial production process, there are many places where the liquid levels have to be controlled and then manipulate the liquid level to maintain accurately for a given value. The conventional controller methods use a classical PID method and the advanced control strategies include IMC and MPC. In this paper, the tuning is done using Z-N method, modified Z-N method, T-L method, CHR, IMC and MPC and the result have been compared in terms of time domain specifications.

II PROCESS DESCRIPTION

The level control trainer kit with DDC and SCADA type of control for codes 313 and 313A respectively. It enables communication to computer about the process variables through RS232 cable. The level transmitter used is a 2 wire capacitance type with range of 0 to 300mm and output in the range of 4 to 20 mA. The I/P converter converts the input in the range of 4 to 20mA to output pressure in the range of 3 to 15 psig. The control valve is operated by this pneumatic signal in the range 3 to 15 psig. It is of air to close type with linear characteristics. The process tank has a calibrated scale with 0- 100% scale. The dimension of the process tank is 440Wx445Dx750H mm .The flow rate is determined by the Rotameter which provides the flow rate in the range of 0-100LPH.The Air filter regulator is in the range of 0-2.5Kg/cm^2 and the range of pressure gauge in the level system is 0-7Kg/cm^2 ,that is 0-2.5g/cm^2.The control module has ADC/DAC module for conversion of the signals and provide the converted output to the control station which is the computer station.

The process setup consists of a supply water tank fitted with pump for water circulation. The level sensor is fitted on a transparent process tank which is controlled by adjusting water flow to the tank by pneumatic control valve. These units along with necessary piping and fittings are mounted in support housing designed to stand on bench top. The

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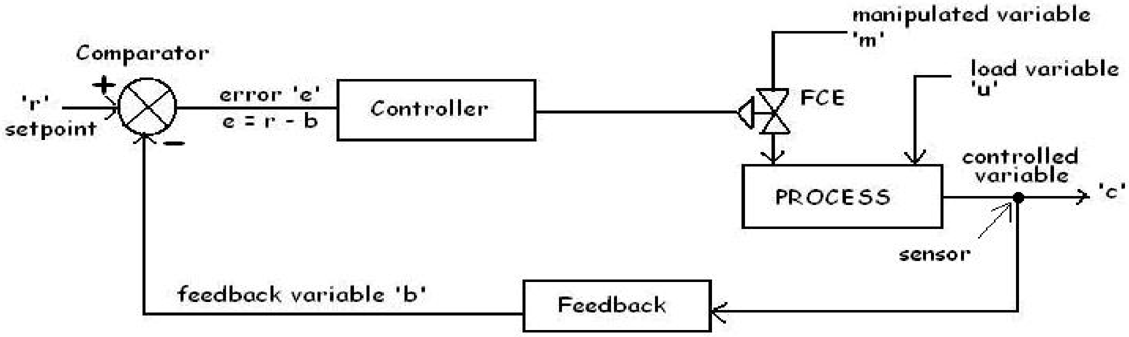
control house includes process indicator or microcontroller, output indicators, power supply for the level transmitter, control switches etc., and the process parameter is controlled through computer or microprocessor based type of controller by manipulating water flow input to the process. The controller used here is direct controller that is as the error increases the controller output also show a proportional increase.

In this work, the controller used for the control of level maintained at the set point is PID controller. The conventional method involve the PID control strategy which is also called as Three term controller. It is basically related to three terms Proportional, integral and derivative constants abbreviated as kp, k_i and k_d respectively. The kp reduces the rise time but it will not completely eradicate the steady state error. K_d will have effect on overshoot and improved performance.ki will completely eliminate the steady state error but will affect the transient response in overall. The PID control is compared with the advanced control strategies such as MPC and IMC.



PROCESS CONTROL LOOP

The set point r is the required level to be achieved and maintained in the tank. The process output is measure by a sensor and this feedback variable 'b' is fed as an input to the comparator. The comparator compares the set point with the feedback variable and the difference between them is fed as input to the controller The controller controls the flow to tank based on the error 'e'. The load and manipulated variable are represented as 'u' and 'm' correspondingly.

The process control loop variables are measured by a suitable sensor and there can be any number of control loops for a process.

III TUNING STRATEGIES

ZEIGLER-NICHOLS METHOD:

Zeigler-Nichols method is probably the most known and the most widely used method for tuning of PID controller. It is a trial and error kind of method. This method is based on sustained oscillations. Z-N is also known as online (or) continuous cycling (or) ultimate gain tuning method. The design criterion for this method is ¼ decay ratio that is quarter decay ratio. It is preferred for PID control loops as it has enhanced disturbance rejection[2].

Z-N method does not require process model but it forces the process into a condition of marginal stability that may lead to unstable operation.

It requires the determination of the dynamic characteristic and then the tuning parameters or factors, to result in the necessary response. The proportional gain can be positive or negative but the first step is to provide a step input and note the steady state value at which it settles. This output determines the proportional gain which is positive ,if the steady state gain is positive. This is done manually for the parameters to be determined and initially with proportional mode ,on.

The formula for tuning in ZN method is represented in Table1

Controller Type	K_c	τ_d	τ_i
P	$0.5K_u$	-	
PI	$0.45k_u$	$P_u/1.2$	-
PID	$0.6k_u$	$P_u/2$	$P_u/8$

TABLE.1

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ZN is the first method to bring control of the system to a practical approach. The gain required t bring the system to continous oscillation in P mode only is correspondingly the ultimate gain, K_u and p_u is the oscillation period.

MODIFIED Z-N METHOD:

Modified Z-N settings is preferred in control loops, where the measure of oscillation provide by ¼ decay ratio and the corresponding large overshoots for set point changes are undesirable. It is also suitable for fractional PI controllers. It is preferred for better response[1].

It is meant to reduce the frequency objective function with a constraint subject to sensitivity function. The formulae for the determination of tuning parameters are mentioned in the table that immediately follows.

Controller Type	K_c	τ_d	τ_i
Some overshoot	$0.33K_u$	$P_u/2$	$P_u/3$
No overshoot	$0.2k_u$	$P_u/2$	$P_u/3$

TABLE.2

It is meant to reduce the frequency objective function with a constraint subject to sensitivity function .In this method the K_u and P_u determined for PID tuning with some overshoot or with no overshoot.

TYREUS-LUYBEN METHOD:

The Tyreus-Luyben method is a method, which is similar to Z-N method but the final controller settings are different. Also, this method only proposes settings for PI and PID.

Controller Type	K_c	τ_d	τ_i
PID	$K_u/3.2$	$2.2P_u$	$P_u/6.3$

TABLE3

These method is based on ultimate gain and period. This method gives no overshoot but gives a very high settling time with respect to the K_u and P_u**.**

THE C-H-R METHOD:

The open-loop Z-N method is modified and proposed by Chein - Hrones and Reswich, which is known as CHR method. This method was developed in the early 1952.They use a design criterion that “quickest response” without overshoot or “quickest response” with 20% overshoot. The tuning procedure is similar to Z-N method. In many process industries, this method is followed for its quick response with minimised overshoot .It is based on the principle of IMC[3].It basically emphasise on disturbance or load rejection, set point tracking[1].

The tuning parameters of this method without overshoot and with 20% overshoot are summarised in the table4.

Controller Type	K_c	τ_d	τ_i
PID(0 % overshoot)	$\frac{0.95}{k}\frac{\tau}{d}$	2.4d	0.42d
PID(20% overshoot)	$\frac{1.2}{k}\frac{\tau}{d}$	2d	0.42d

TABLE4 (Load Rejection)

In this method represents the delay time represents the process gain and T represents time constant which is 63025 of final value. These parameters can be determined from the

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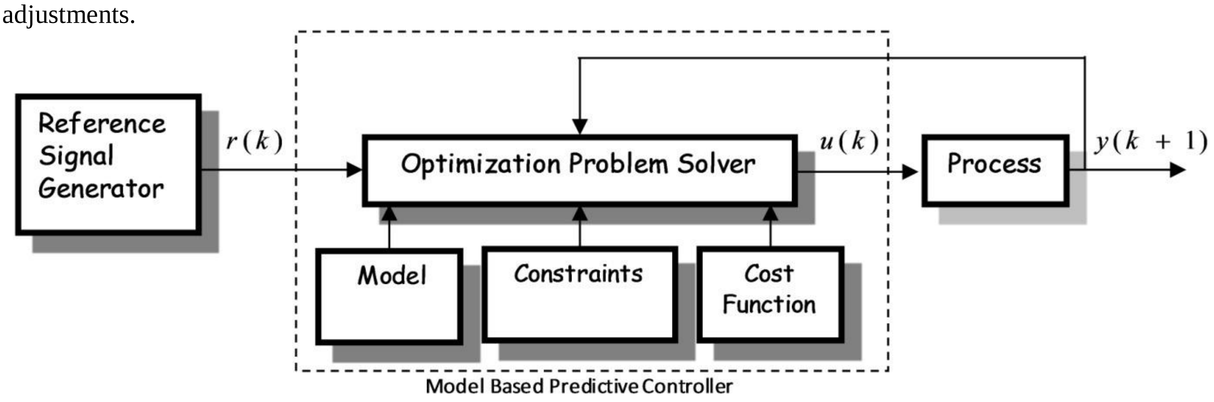
Controller Type	K_c	τ_d	τ_i
PID(0 % overshoot)	$\frac{0.6}{k}\frac{\tau}{d}$	τ_m	0.5d
PID(20% overshoot)	$\frac{0.95}{k}\frac{\tau}{d}$	1.4 τ_m	0.47d

TABLE 4 (Set point Tracking)

The main objective of a controller in feedback is set point tracking and disturbance rejection. A controller designed for disturbance rejection forces the process parameter to reach the set point irrespective of the disturbance. And set point tracking type of controller finds its application in cases where set point increases or decreases and based on the process variable is adjusted to provide the necessary control action.

MODEL PREDICTIVE CONTROL:

Many process industries such as chemical plants, refining/petrochemical industries and oil refineries uses an advanced method of process control known as Model Predictive Control (MPC). MPC criterion depends on dynamic models of the process. Only good process models and system identification results to the success of MPC.MPC predict the future response of a plant. MPC optimize the future plant behaviour by calculating a series of future manipulated variable adjustments.



There are three main approaches to model predictive control. They are MAC (Model Algorithmic Control), which depends on the impulse response of the system, DMC (Dynamic Matrix Control), which utilises the step response samples of the process, and GPC (Generalized Predictive Control), which is based on the transfer function of the process. Among the three approaches ,DMC methods is more popular and implemented in process industries as acquiring the step response samples is easier than transfer function or impulse response of the process.
The state estimator estimates the current and previous state output of the process for comparison with the set point continuously. It is the major block in the model predictive controller. The cost function is also one of the constraints or input to the optimization solver .The output from the process is compared with the model and based on the error the process remains under control.
The important pros of MPC are that they are able to find most economical set points and point of operation, they ensure minimal maintenance and alarm annunciating facility in case of future problems.

INTERNAL MODEL CONTROL:

This method was developed in the year 1980 by Garcia, Morari[1].IMC is another model based controller used in many industries. IMC make use of a process model to infer the effects of immeasurable disturbance on the process output and eliminate that effect. The IMC controller consists of an inverse of the process model.
IMC is a model based control technique. We develop a model-based procedure, where a process model is embedded in the controller by explicitly using process knowledge, by virtue of the process model, improved performance can be obtained. The formulae for manipulation in IMC control is as follows:

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Controller Type	K_c	τ_d	τ_i
IMC	$\frac{2\tau + d}{2(\lambda + d)}$	$\tau + \frac{d}{2}$	$\frac{\lambda d}{2\tau + d}$

TABLE 5

In this method, λ is a performance parameter defined by user choice,T is the time constant and d is the delay time. They can be determined from the response curve.

IV PERFORMANCE INDICES CALCULATION

MINIMUM ERROR INTEGRAL CRITERIA:

Tuning for ¼ decay ratio often leads to oscillatory responses and also this criterion consider only two points of closed loop response. The controller can also be design based on performance index. Some of the performance indexes are:

1. Integral of the absolute value of the error(IAE):

   $$IAE= \int_0^\infty |\, e(t)|dt$$

   It eradicates the small error which means it provides a very little overshoot. It has less oscillations[1].

2. Integral of the square value of the error(ISE):

   $$ISE= \int_0^\infty e(t)dt$$

   It integrates the square of errors. this implies that large errors get even larger on squaring and gets eliminated while the small errors will exist for a longer time.

3. Integral of the time weighted absolute value of the error(ITAE):

   $$ITAE= \int_0^\infty t\, |e(t)|dt$$

   In case of large amplitudes, it amplifies small errors but it is slower than ISE criteria.

4. Integral of the time weighted square value of the error(ITSE):

   $$ITSE= \int_0^\infty t\, e2(t)dt$$

   ITSE and ITAE criteria have extra error multiplier that emphasis on errors that exist for a longer time and hence these find its application in many processes.

V RESULT AND DISCUSSION

The transfer function defined from diverse methods were simulated in MATLAB as PID controlled process .The simulated block diagrams was implemented in MATLAB environment using different conventional control algorithm and model based control technique. Different control methods have a different output response t for a unit step input. The ZN method is kind of trial and error method and its a time consuming method. It is also not applicable to processes that are unstable and open loop. It insists the process to be unstable for any set point change or due to any external disturbances.

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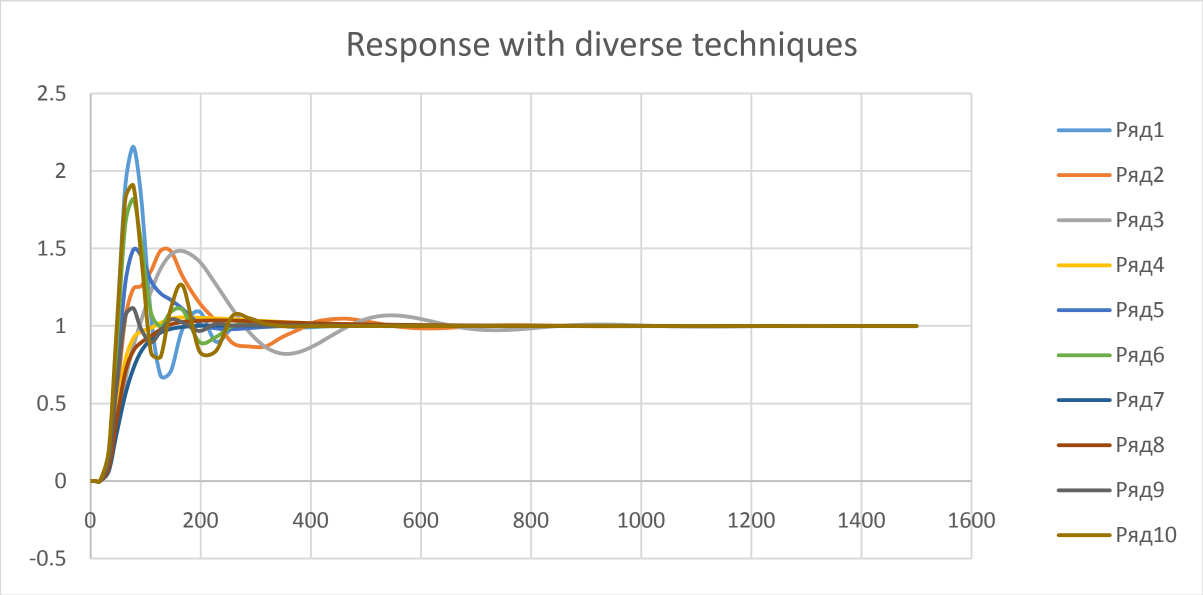

The chart provides a comparative space for analysis of controller with different methods for a single cylindrical tank level process. The different methods are recognised by their different series colour. The series 1 to series 10 correspondingly stand for ZN method, Modified ZN(with overshoot),Modified ZN(with no overshoot),Tyres Luyben method .C-H-R method(Load rejection) 0%,C-H-R method (Load Rejection)20%,C-H-R method (set point Tracking)0%,C-H-R method(set point tracking)20%,IMC method and MPC method.

The time domain specifications are defined from the graph and are tabulated as in table 6.

TUNING CONTROLLER	PEAK OVERSHOOT	PEAK TIME	RISE TIME	SETTLING TIME
Zeigler-Nichols	1.15	77	42.51	360
Modified ZN(Some overshoot)	0.5	140	74	720
No overshoot	0.5	160	90	1240
TL	0.059	200	131	980
CHR(Load Rejection) 0%	0.479	80	55.5	384
20%	0.735	81	50	350
CHR(Set Point Tracking) 0%	0.042	215	150	1380
20%	0.07	65	63	560
IMC	0.85	65	47.75	354
MPC				240

TABLE 6

From the table ,it can be clearly understood that MPC is suitable for level process control as it has the minimal settling time and reduced overshoot. The time domain specifications considered for comparison are peak overshoot, settling time, rise time, peak time.

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The comparison of performance indices on the different techniques is represented in table.7

CONTROLLER METHOD	ISE	IAE	MSE
Ziegler-Nichols	305.4085	257.3462	0.9757
Modified ZN(Some overshoot)	296.3378	237.5796	1.0451
No overshoot	272.0205	272.1714	1.0451
TL	280.9931	280.3197	0.7356
CHR(Load Rejection) 0%	285.9747	270.0000	0.8401
20%	249.3440	294.2629	0.9807
CHR(Set Point Tracking) 0%	280.5777	281.4813	0.7218
20%	275.1120	258.5871	0.8642
IMC	302.7569	247.0703	1.0058
MPC	247.8537	241.7100	0.6168

TABLE 7

The performance indices tabulated for process with diverse methods show that the MPC control is suitable as the ISE and MSE are comparatively low .C-H-R method with load rejection 20% show a similar result but it is slower than MPC control.

VI.CONCLUSION

MPC controller has proven it for better control of a single cylindrical tank level process .It has taken little settling time which implies that it is faster than the conventional methods. It also has comparatively minimum overshoot .ZN method also provide good control over the process but it shows slower control than MPC control. Modified ZN method gives a response with reduced overshoot but slow, that is high settling time. Tyres Luyben and C-H-R method show high overshoots. Hence it can be concluded that MPC is suitable for single tank level process based on the performance indices and time domain specifications.

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