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Comparison of tuning PID controller for nonlinear Spherical tank using GA and IMC

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Abstract

The work concentrates on comparing the results of tuning PID controller values using genetic algorithm and IMC for a nonlinear spherical tank process. Controlling level of a nonlinear tank is a tedious and important process in various process industries. Conventional PID controller is the simplest controller used nowadays; even though there are many classical methods for tuning PID values they are not accurate in all operating ranges. This paper focus on comparing the response of Internal model controller (IMC) with Genetic algorithm and establishing the best controller. GA values are tuned using IMC values as base values and the mathematical modeling of spherical tank is done by using mass balance equations. The tuning is done in MatLab and the real time process is carried out in LabVIEW.

Keywords: PID controller, IMC (Internal model controller), GA (Genetic algorithm), MatLab, LabVIEW.

1. Introduction

Control of parameters such as flow, level, temperature etc. in industries is still ambitious. Depending on the dynamics the process is classified into linear and non-linear process. In level process cylindrical and cubical are linear process but they are not only used in industries, nonlinear tanks such as conical and spherical are also used. We have taken spherical tank for the examination process.

Most of the industries are dependent on P+I+D controller because it is the simplest controller for tuning and controlling. There are many classical methods available for tuning PID controller values such as Z-N (Ziegler-Nichols), C-C (cohen-coon) etc. but they are not accurate and non linear systems need some high level controller tuning methods such as IMC, GA etc.

In PID controller we check the controllability using step responses of the closed-loop systems and comparing the overshoot, rise time and settling time. An alternative is to use the integral error as a performance index.

However, these time domain performance measures do not address directly another important factor of a closed-loop system—robustness.

It is a well-known fact that models used for controller tuning or design are often inaccurate, so a PID setting based on optimization assuming an accurate model will generally not be guaranteed to be robust.

For a fair comparison of different PID settings, both time domain performance and frequency domain robustness should be considered.

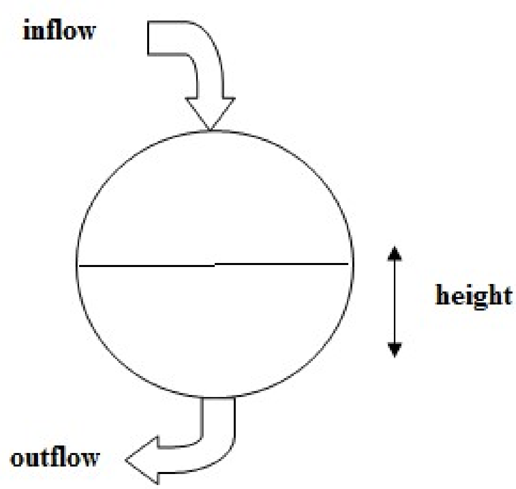

Figure 1. Spherical Tank

2. Mathematical modeling of spherical tank

Consider a spherical tank, as shown in figure, of radius R. The water flows in at a rate Fin and flows out at a rate Fout.

Volume of a sphere is given by, V= $\frac{4}{3}\pi h^3$

The first order differential equation of the system is given by,

F_i- flow rate at inlet of the tank

F_o-flow rate at outlet of the tank

h- Height of the liquid in the tank

R- Resistance to flow

F_o= h/R

A =area of cross section area of tank

$A\frac{dh}{dt} = F_i - F_o = F_i - h/R$

$AR\frac{dh}{dt} + h = R F_i \longrightarrow 1$

At steady state

$H_s = R F_{i,s} \longrightarrow 2$

In terms of deviation variables from 1 and 2

$AR\frac{dh'}{dt} + h' = RF_i'$

Where $h' = h - h_s$ and $F_i' = F - F_{ts}$

$T_p = AR \longrightarrow$ time constant the process

$K_{P=}$R=steady state gain of the process

Transfer function

$G(s)=h'(s)/F_i'(s)=k_p/\tau s+1$

$G(s) =H(s)/Q(s)=R/ \tau s+1$

Where

Time Constant = Storage Capacity x Resistance to flow.

3. Process description:

Table 1: spherical tank specification

Parameter	Description	Value
D	Diameter	18
R	Radius	9
H	Height	9
Fin	Maximum flow rate	60 lph

The above figure shows the spherical tank with inlet valve and outlet valve the liquid is passed through inlet valve using rotameter and the characteristics is obtained using open loop configuration and the graph is obtained. Using the graph the transfer function is obtained for flow level 30.

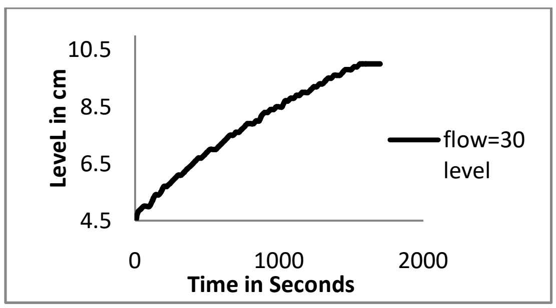

Figure 2: open loop response

From the open loop response, the obtained transfer function is

$$\frac{1.12e^{-5s}}{820s+1}$$

4. Internal Model Control Method

The internal model control philosophy relies on the internal model principle, which states that control can be achieved only if the control system encapsulates either implicitly or explicitly, some representation of the process to be controlled. Morari and his co-workers have developed an important new control system strategy that is called internal model control or IMC. The IMC approach has two important advantages: a) It explicitly takes into account model uncertainty and (b) it allows the designer to trade-off control system performance against control system robustness to process changes and modeling errors.

Table 2: IMC Tuning Formula

K_p	T_i	T_d
$\frac{\tau}{(0.5\tau_d + \tau_{c1})K_p}$	T	$\frac{\tau_d}{2}$

5. Genetic Algorithm

Genetic algorithms are used in finding ideal solutions for non-linear systems [5]. It is also used for tuning PID controllers. Genetic algorithms used to find the best solution from the set of possible solutions known as population. Genetic algorithm composed of two functions namely encoding scheme and evolution function. The encoding scheme is used to find set of solutions. Primarily a set of chromosome are installed and they are set to random value. From the evolution process subsequent generation are created from population and process is completed after reaching predefined value.

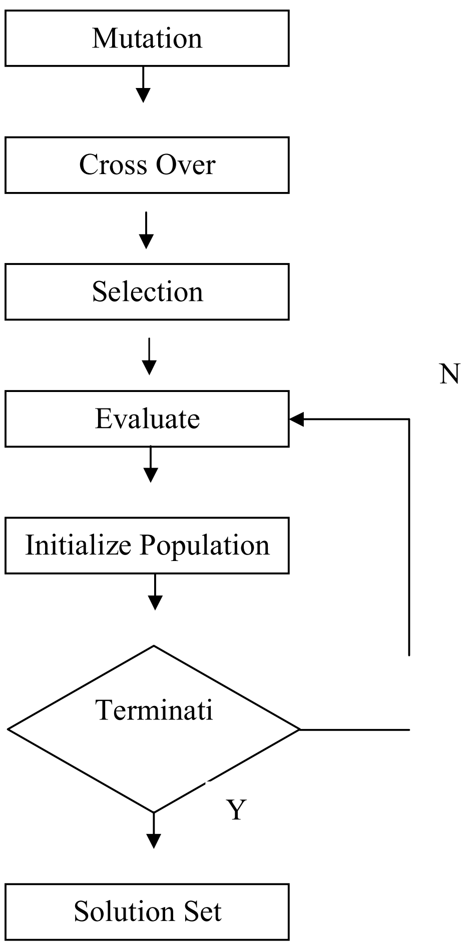

Figure 3: flow chart of GA

6. Implementation of GA

The optimal values of the PI controller parameters Kp, Ki are found using GA. All possible sets of controller parameter values are chromosomes whose values are adjusted so as to minimize the objective function, which in this case is the error criterion (GirirajKumar S. M., Sivasankar R., Radhakrishnan T. K., Dharmalingam V. andAnantharaman N,2008).

6.1 Selection of GA parameters

To start up with GA, predefining certain parameters need to be defined. It includes the population size, bit length of chromosome, number of iterations, selection, crossover and mutation types etc. Selection of these parameters decides to a great extent the ability of designed controller.

6.2 Performance Indices for the Algorithm

The performance of a controller is best evaluated in terms of integral of time absolute error criterion. A number of such criteria are available and in the proposed work, controller's performance is evaluated in terms of:Integral of Time multiplied by Absolute Error (ITAE) criterion, given by:

$$\text{ITAE} = \int_{0}^{T} t|e(t)|dt$$

7. Termination Criteria

Optimization algorithm will automatically terminate execution either when the number of iterations gets over or with the attainment of acceptable fitness value. Fitness value, in this case is nothing but reciprocal of the magnitude of the objective function, since we consider for a minimization of objective function. In this paper the termination criteria is considered to be the attainment of acceptable fitness value which occurs with the maximum number of iterations as 100.For each iteration the best among the 100particles considered as potential solution are chosen Therefore the best values for 100 iterations for four models are sketched and shown in figure3, figure4, figure5 and figure6 with respect to iterations

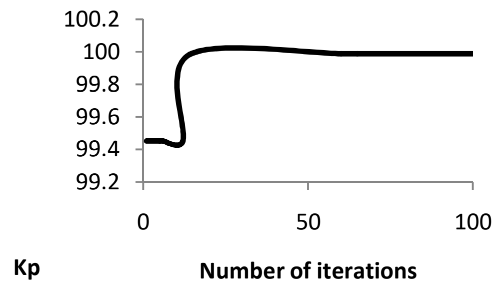

Figure 4. Best solutions of Kp=99.9 for 100 iterations

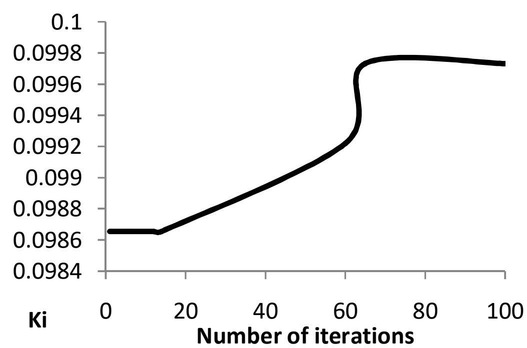

Figure 5. Best solutions of Ki=0.0997 for 100 iterations

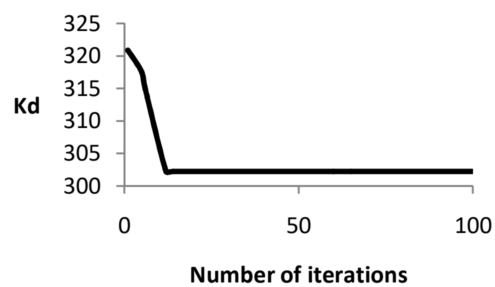

Figure 6. Best solutions of Kd=302.2 for 100 iterations

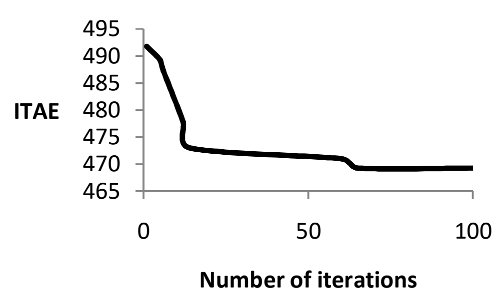

Figure 7. ITAE for 100 iterations

8. Results and Comparison

The Genetic algorithm based PID controller is compared with IMC based on time domain specifications and performance indices.

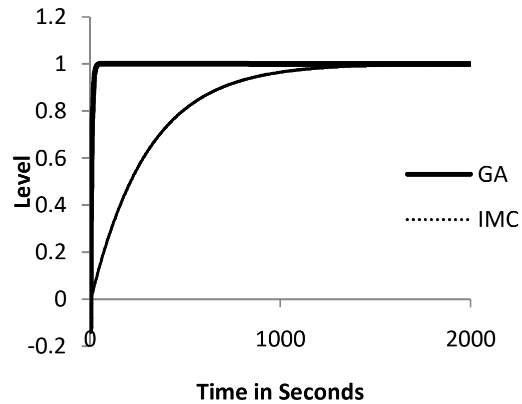

Figure 8. Closed loop response of GA & IMC

Table 3: Comparison of time domain specifications:

Tuning method	Rise time	Settling time	Peak time	Peak overshoot
IMC	1700	2000	0	0
GA	47	47	0	0

Table 4: Comparison of performance index:

Tuning method	ISE	IAE	ITAE	MSE
IMC	1.5002e+003	2.880e+003	7.856e+005	0.1674
GA	55.6074	74.1946	412.7893	0.5389

From the above time domain specifications GA has minimum settling time compared to IMC and the performance index of GA is far better than IMC so the proposed controller is GA.

Conclusion

The obtained transfer function is processed by PID controller tuning method using three parameters such as proportional band, integral time and delay time and from that proportional gain, integral gain and derivative gain are obtained. The values obtained from different tuning methods are simulated using MATLAB and the corresponding time domain specification and performance index are tabulated. From the tabulation it is clear that GA have better efficiency when compared to IMC for instance it is clear that it has the least settling time than any other tuning methods possess. So from that it is concluded that GA is the suitable and efficient controlling method for nonlinear spherical tank system further its scope is vast for other applications too.

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