I J C T A, 8(5), 2015, pp. 2247-2252

Particle Swam Optimization based PID controller parameters for multivariable non linear system

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Abstract: In process industry, most of the processes are non linear systems. These processes are producing many problems such as time delay, non-linearity, poor damping and higher order etc. Controlling the process from nonlinearity and time varying characteristics are the highly challenging control tasks in the chemical process industries. Therefore the controllers are performing an important role in industrial processes. Multiloop PI and PID controllers are widely used in process industry. In this work tuning of multiloop PI and PID control system is applied for a MIMO system. The PI and PID controller parameters such as K_p, K_i and K_d are optimally tuned for the wood berry distillation column using particle swam optimization technique and its results are compared with Ziegler and Nichols (ZN) technique. The performances of the processes are carried out in the simulation environment using matlab.

Keywords: PID Controller, Optimization, ZN technique, Particle Swam optimization (PSO), Wood-Berry distillation column.

1. INTRODUCTION

Distillation columns are used for separation in process industry. Distillation is a versatile process that is used in many varieties of industries to separate mixtures of different chemical species. It is widely used in petroleum, oil and gas production, chemical and pharmaceutical industries [1, 2]. Distillation operates by the application and removal of heat to exploit differences in relative volatility. The heat vaporizes the component which has low boiling point and high volatility and leaves the less volatile component as liquid. It is easy to separate the mixtures with high relative volatilities. This makes difficult to separate the close boiling and azeotropic feeds. So distillation techniques are used to separate these mixtures.

Distillation column used to separate only two components called binary distillation column. That is the feed mixture consists of two components with different volatilities. The columns are very costlier to manufacture and its running cost also huge amount because of the heat requirements. Therefore the distillation columns are designed to operate with very good efficiency.

In process industries, to efficiently operate a distillation column controllers like PI or PID controllers are used to control the column parameters [3]. Even thought PID controllers are widely used in process industry, it is difficult to tune the controller parameters if the process is getting the problems such as non linearity, higher order, time delay etc. By tuning the controller parameters we may achieve the desire response. There are many empirical tuning rules in process control to tune the PI and PID controller parameters. But they are not bringing the efficiency of the column in a satisfactory manner. The optimal tuning of controller parameters is essential to get the purified product from a distillation column.

Designing controllers for MIMO systems has attracted many research interests. Many multivariable control approaches such as simulated annealing, genetic algorithm, differential evaluation and ant colony

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etc have been proposed [11]. Genetic algorithm is a search and optimizes the non linear controller parameter in a probabilistic manner. All other methods are applied for SISO systems but most of the process industries are working with multi input multi output systems. In this work a new approach called particle swam optimization technique is used to tune the PID controller parameters. It gives less error than the conventionally tuned methods. It also gives less settling time and overshoot.

2. PROCESS DESCRIPTION

Wood-Berry distillation column is taken for evaluating the proposed particle swam optimization approach. It is a binary distillation column used to separate methanol and water from a feed. It is a highly non linear process with strong interaction between input and output. The schematic diagram of wood berry distillation column is shown in Fig.1.

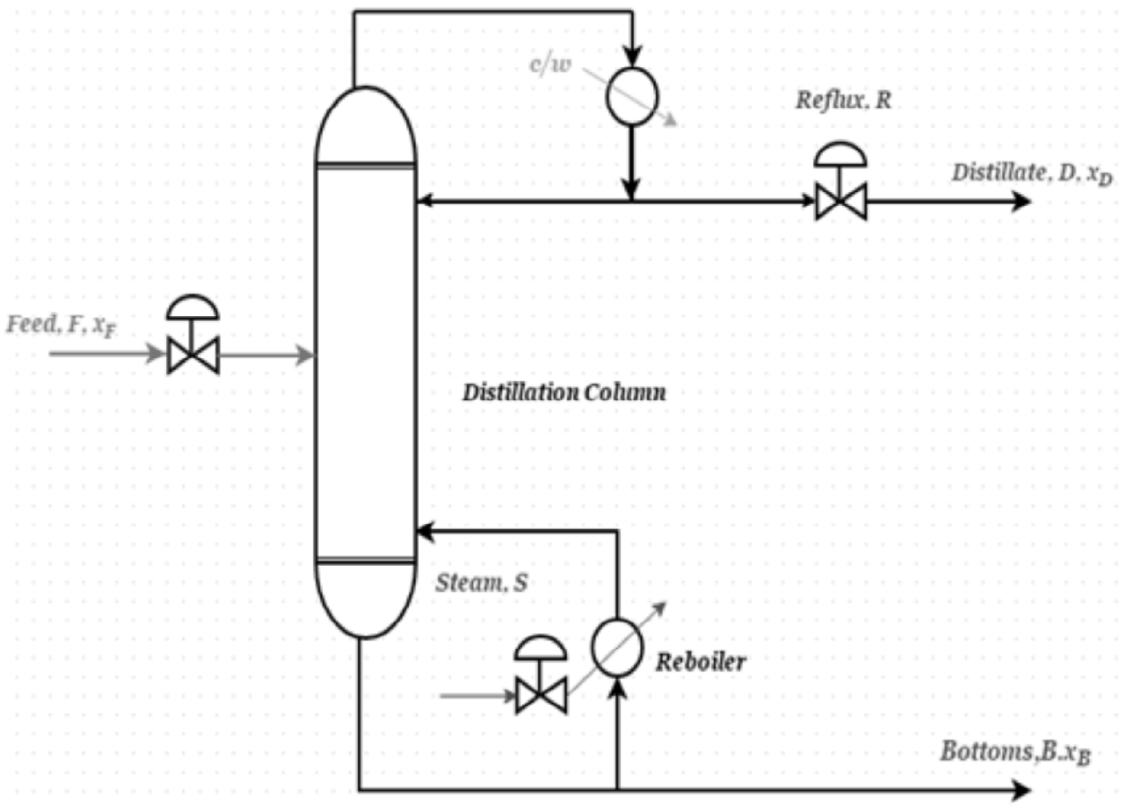

Figure 1: Schematic diagram of wood berry distillation column

Distillation columns are an important chemical unit hence their operation must be in well efficient to give almost pure components. Wood berry distillation column is modeled experimentally by wood and berry with a 9 inch diameter, 8 tray distillation column in 1973. It has a transfer function model of 2*2 matrix model. It is a first order with time delay system with multiple inputs and multiple outputs. There are two inputs and two outputs. The compositions of top and bottom products in terms of weight % of methanol are the controlled variables. The manipulated input variables are reflux and reboiler steam flow rates which are expressed in lb/min. The transfer function model is given by the below equation.

$$\begin{bmatrix} y_1(s) \\ y_2(s) \end{bmatrix} = \begin{bmatrix} \frac{12.8e^{-s}}{16.7s+1} & \frac{-18.9e^{-3s}}{21.0s+1} \\ \frac{6.6e^{-7s}}{10.9s+1} & \frac{-19.4e^{-3s}}{14.4s+1} \end{bmatrix} \begin{bmatrix} u_1(s) \\ u_2(s) \end{bmatrix} + \begin{bmatrix} \frac{3.8e^{-3.1s}}{10.9s+1} \\ \frac{4.9e^{-3.4s}}{13.2s+1} \end{bmatrix} D(s) \quad (1)$$

Where reflux flow rate $u1$ and steam flow rate $u2$ are the input signals, the output signals are the top product composition y*1* and bottom product composition $y2$ in mole fraction. The process disturbance is the feed flow rate D. This linear transfer function model is valid around the set point $y1 = 0.96$ and $y2 = 0.02$. The time sampling is 1 min.

3. DESIGN OF CONTROLLERS

The PI and PID controllers are designed in this work. There are three components in a PID controller such as proportional term, integral term and derivative term. In PI controller, derivative term is not available. The three term values are represented by K_p, K_i, and K_d respectively. The suitable values of these controller parameters give stability of the system and operate the distillation column with good efficiency and economically. It also improves the time domain responses.

A controller compares the actual value of the plant output with the set or reference input. After comparison the controller gives the deviation that is called error signal. In accordance with the error signal the controller produces a control signal that will decrease the deviation to minimum value [4]. The control signal is otherwise called as the control action of the controller.

The control action of a proportional plus integral controller is defined by

$$u(t) = Kp\ e(t) + \frac{Kp}{Ti}\int_0^t e(t)dt$$

The combination of proportional control action, integral control action, and derivative control action is termed proportional-plus-integral-plus-derivative control action. It has the advantages of each of the three individual control actions. The equation of a controller with this combined action is given by

$$u(t) = Kp\ e(t) + \frac{Kp}{Ti}\int_0^t e(t)dt + Kp\ Td\,\frac{de(t)}{dt}$$

Where Kp is proportional gain,

$Ki = Kp/Ti$ is integral gain,

$Kd = Kp*Td$ is derivative gain

Ti is integral time and Td is derivative time

The control action produced by the PI or PID controller is given to the plant to give the desire output. Until to reach the steady state, this procedure continues [5, 6, 7, 8 & 9]. The PID controller general stucture is shown in Fig.2.

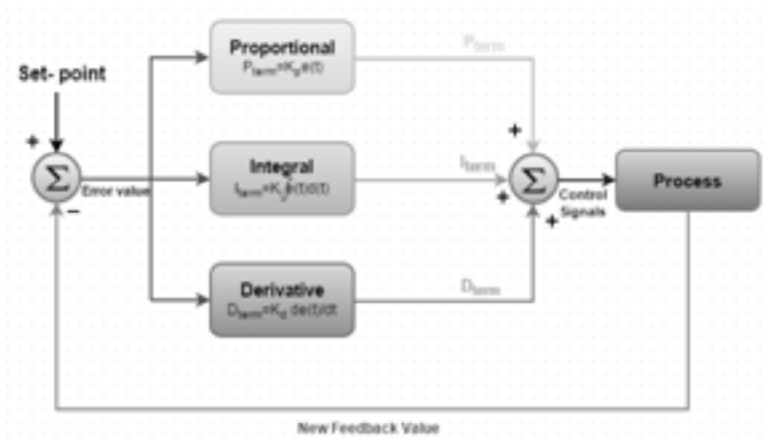

Figure 2: General structure of PID controller

4. TUNING METHOD

In this work, first conventional PI and PID controllers are designed using the Ziegler / Nichols tuning method [10]. The controller parameters *Kp*, *Ki* and *Kd* values are determined and applied for wood berry distillation column which is the process consider for evaluation. The determined controller parameter values are tabulated in Table 1. The system output is not satisfied in efficient and economical aspects.

Then the proposed method is applied to tune the controller parameters by optimally. The block diagram of the proposed method is shown in Fig.3. The particle swam optimization method of tuning is proposed to the multivariable non linear system called wood berry distillation column.

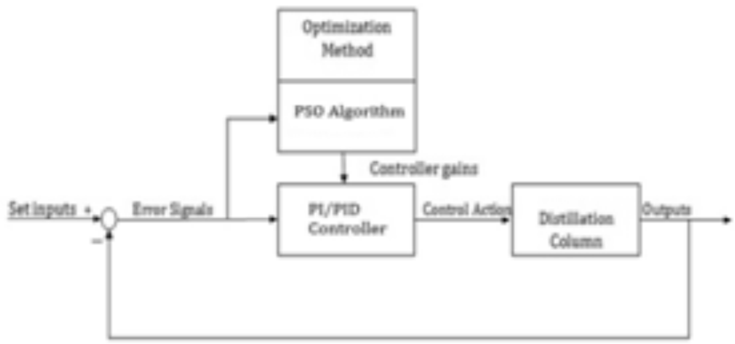

Figure 3: Block diagram of PSO tuned controller design

The proposed method particle swam optimization is introduced by Kennedy & Eberhart in the year 1995. It is based on the inspiration of social behavior and movement dynamics of insects, birds and fish. In PSO algorithm, all the particles are placed at random position and are supposed to move randomly in a defined direction in the search space. Each particle's direction is then changed gradually to insist to move along the direction of its best previous positions to discover even a new better position with respect to some fitness measures. Both the initial velocity and position of the particle are chosen randomly and updated using the following equation,

$$V = wV + c_1 R_1 (p_b - X) + c_2 R_2 (g_b - X) \tag{2}$$

$$X = X + V \tag{3}$$

Where, V-Velocity of the particle

X-Position of the particle

R_1, R_2 -random numbers in range (0,1)

w-Inertia weight

c_1-Cognitive parameter

c_2-Social parameter

This PSO method has been successfully applied in many real-world engineering applications, it is widely held that PSO algorithm gets trapped in global optima.

5. SIMULATION RESULTS

The determined controller parameter values are applied to the selected wood-berry distillation column process and the performances are verified. The PI, PID and PSO based PID controllers performances and results are compared

The control action for top product is reflux flow rate u1 and bottom product is stream flow rate u2.. That control actions of PI, PID and PSO tuned PID controller are shown in Fig.4 and Fig.5

Table 1
Tuning values

Controller Parameters	*PI Controller*	*PID Controller*	*PSO tuned PID*
$K_{p,1}$	1.9866	1.9866	2.0137
$K_{i,1}$	0.2643	0.4643	0.9543
$K_{d,1}$	-	1.0242	0.8661
$K_{p,2}$	-0.2254	-0.2254	-0.2289
$K_{i,2}$	-0.07008	-0.1008	-0.0573
$K_{d,2}$	-	-0.4123	-0.4139

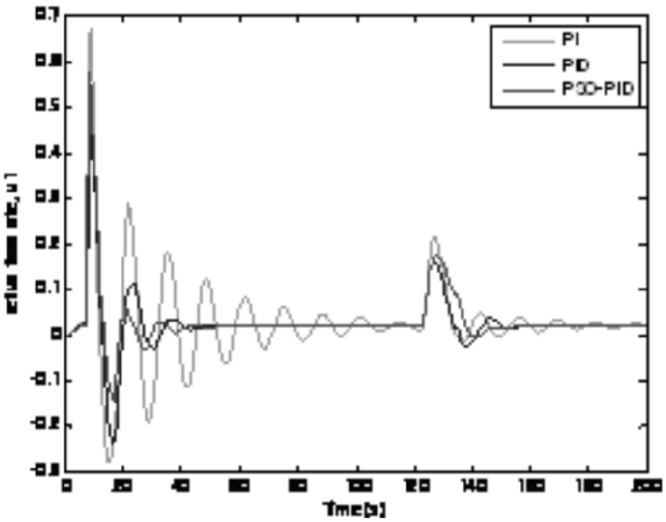

Figure 4: Control action of top product

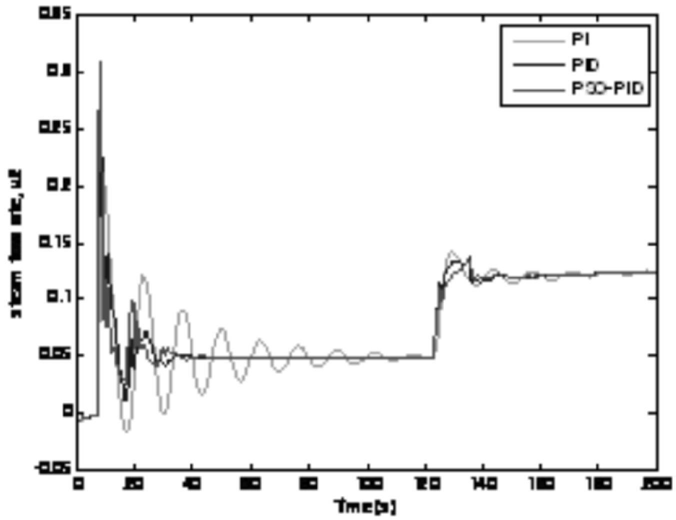

Figure 5: Control action of bottom product

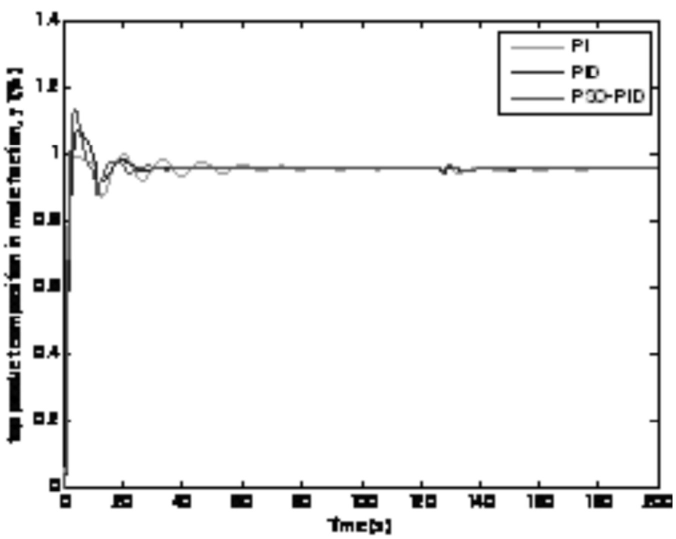

Figure 6: Output response of top product

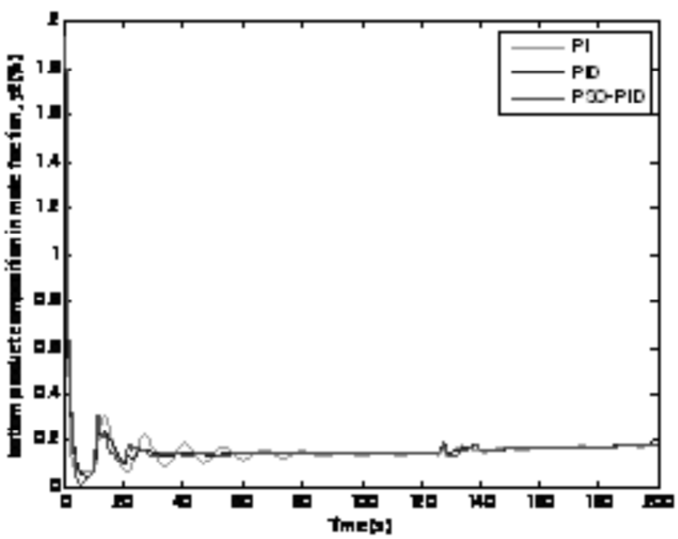

Figure 7: Output response of bottom product

The servo and regulatory responses of top and bottom products of wood berry distillation column are given in Fig.6 and Fig.7. At time 120second, the disturbance is given.

The performances are analysed and tabulated in Table 2 for top and bottom products of PI, PID and ABC tuned PID controllers.

Table 2
Performance analysis of top and bottom products

Criteria	*Top product*			*Bottom product*		
	PI	*PID*	*PSO tuned PID*	*PI*	*PID*	*PSO tuned PID*
Rise Time	53.5785	36.7630	36.0138	179.172	173.1085	173.4492
Settling Time	2.5069	3.6544	2.7357	3.0657	5.9611	8.0765
Peak Overshoot	1.0009	1.0778	1.1390	0.6723	0.4995	0.5769
Undershoot	0	0	0	1.4319e+003	1.1559e+003	687.9396

6. CONCLUSION

In this work wood-berry distillation column process was studied, analyzed and simulated. The conventional PI, PID and PSO tuned controllers were designed independently to control the process. The conventional PI, PID controller outputs were oscillating and more overshoot but PSO tuned PID controller outputs resembles with less settling time and less overshoot. Therefore while comparing conventional PI, PID, PSO tuned PID controller, PSO tuned PID controller was given better performance than conventional controllers. All these simulations were done by MATLAB tool in windows 8 operating system.

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