OPTIMAL PI CONTROLLER DESIGN FOR DOUBLE TANK SYSTEM

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Abstract— In this contribution, Jaya algorithm based PI controller is proposed for level control of double tank system. For designing the PI controller, integral of squared error is considered as design criterion. The ISE of unit step input is minimized using the Jaya algorithm. For comparison purpose, the responses and time domain specifications of system are obtained. The simulation results show that the Jaya based tuning of PI controller is performing satisfactory.

Keywords— ISE, Jaya algorithm, Optimization, PI controller, Tuning.

I. INTRODUCTION

Various rule based and artificial intelligence based methods have been proposed in literature for tuning the parameters of proportional-integral-derivative (PID) controllers. Rule based methods [1, 2] include Ziegler-Nichols (ZN) criterion, integral of square time weighted error (ISTE), Kessler Landau Voda (KLV), some overshoot (SOOV) rule, no overshoot (NOOV) rule, Mantz-Tacconi Ziegler-Nichols (MT-ZN) rule, refined Ziegler- Nichols (R-ZN) rule [2], Pessen integral of absolute error (PIAE), etc.

The artificial intelligence based methods include LJ based PID controller tuning for reverse osmosis system [3], PID controller tuning using particle swarm optimization [4,5], PID controller tuning using teacher-learner-based-optimization [6], PID controller tuning with genetic algorithm [7, 8], PID controller tuning with elephant herding optimization [9], evolutionary computation based PID tuning [10], PID tuning using soft computing techniques [11] and colonial competitive algorithm (CCA) based PID tuning [12]. The artificial intelligence based techniques give better time response than rule based methods.

In this contribution, Jaya optimization algorithm based tuning of PI controller for level control of double tank system is proposed. Rao [13], recently, proposed Jaya algorithm which is simple in implementation and has no algorithmic parameters. Being free from algorithmic parameters, it furthers becomes easy to implement the algorithm. Hence, Jaya is tested for tuning the PI controller for level control of double tank system in this contribution. The tuning criterion considered is integral of squared error (ISE) of unit step input. Simulation results present the quantitative as well as qualitative results.

The layout of this contribution is as follows. Section 2 describes the system structure in which the plant and controller descriptions are provided. Section 3 discusses the tuning methodology in detail. The details of Jaya optimization technique is given in section 4. Section 5 presents the simulation results and discussion. Finally, the contribution is concluded in section 6.

II. THE SYSTEM STRUCTURE

The feedback control of double tank system [14] is shown in Fig 1. The transfer functions, C(s) and G(s), respectively, denote the controller and plant.

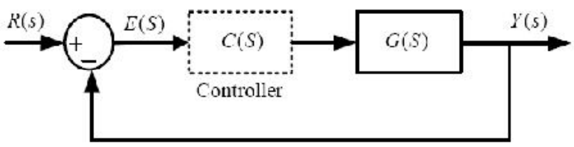

Fig. 1: Feedback system.

The transfer functions of $G(s)$ and $C(s)$ are given as

$$G(s) = \frac{K}{(\tau_a s+1)(\tau_b s+1)} \quad (1)$$

$$C(s) = K_p\left(1+\frac{1}{T_i s}\right) \quad (2)$$

where, K, τ_a and τ_b are, respectively, gain and time constants of double tank system and K_p and T_i are, respectively, proportional gain and integral time constant of controller.

3. The tuning of double tank system

The integral of squared error of unit step input is taken as design criterion for PI tuning of level control of double tank system. The integral of squared error (ISE) is given as

$$J = \int_{t=0}^{t=\infty} e^2(t)dt \quad (3)$$

which can be represented in terms of alpha and beta parameters [9] as

$$J = \frac{1}{2}\sum_{i=1}^{n}\frac{\beta_i^2}{\alpha_i} \quad (4)$$

where α_i and β_i for $i = 1, 2, \cdots, n$ are the alpha and beta parameters [9] obtained from the coefficients of numerator and denominator of Laplace transform of $e(t)$; and n is the order of Laplace transform of $e(t)$.

4. Jaya optimization technique

Recently in 2016, Rao [13] proposed an optimization technique which is simple and easy in implementation. Added advantage of this algorithm is that it is having no algorithm-specific parameters.

The detailed steps of Jaya are given as follow:

Consider a total R candidates in the population and C decision variables. The jth dimension, $j = 1, 2, \cdots, C$ of ith candidate, $i = 1, 2, \cdots, R$, can be written as $X_{i,j}$.

1. Choose the initial population using

$$X_{i,j} = X_{i,j}^{\min} + r_{i,j}\left(X_{i,j}^{\max} - X_{i,j}^{\min}\right) \quad (5)$$

where $i = 1, 2, \cdots, R$ and $j = 1, 2, \cdots, C$; $X_{i,j}^{\min}$ and $X_{i,j}^{\max}$, respectively, denote the minimum and maximum values of $X_{i,j}$; and $r_{i,j}$ represents random numbers in the range $[0,1]$.

2. Update the population by

$$nX_{i,j} = X_{i,j} + r_a\left(X_{best,j} - \left|X_{i,j}\right|\right) - r_b\left(X_{worst,j} - \left|X_{i,j}\right|\right) \quad (6)$$

where, $nX_{i,j}$ is updated solution and r_a and r_b are random numbers in the range $[0,1]$. $X_{best,j}$ and $X_{worst,j}$ denote, respectively, the best and worst candidates.

3. Modify $X_{i,j}$ by $nX_{i,j}$ if $nX_{i,j}$ provides better fitness value otherwise retain $X_{i,j}$.
4. Go to step 2 and repeat until the termination criterion meets.

5. Simulation results

The parameters [14, 15] of double tank system considered in this contribution are given as

$$K = 6,\ \tau_a = 2 \text{ and } \tau_b = 4 \quad (7)$$

The objective function [15] given by (4) takes the following form

$$J = \frac{1}{2}\left\{ \frac{q_1^2}{p_0 p_1} + \frac{q_2^2}{p_1 p_2 - p_0 p_3} + \frac{(p_1 q_3 - q_1 p_3)^2}{p_1 (p_1 p_2 - p_0 p_3) p_3} \right\} \quad (8)$$

$$p_0 = T_i \tau_a \tau_b \quad (9)$$

$$p_1 = T_i (\tau_a + \tau_b) \quad (10)$$

$$p_2 = T_i (1 + K K_p) \quad (11)$$

$$p_3 = K K_p \quad (12)$$

$$q_1 = T_i \tau_a \tau_b \quad (13)$$

$$q_2 = T_i (\tau_a + \tau_b) \quad (14)$$

$$q_3 = T_i \quad (15)$$

The controller parameters obtained by minimizing (8) using Jaya algorithm are given in Table I. The controller parameters proposed in [15] due to LJ based tuning are also provided in Table I. The unit step responses of system are shown in Fig. 2. The time domain specifications are mentioned in Table II.

Table I: Controller parameters

	Proposed PI controller	LJ based PI controller
K_p	661.3612	612.7373
T_i	679.4329	999.9788

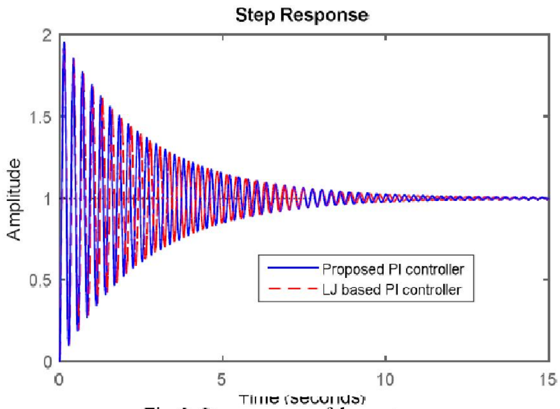

Fig. 2: Step response of the system.

Table II: Time domain specifications

	Proposed PI controller	LJ based PI controller
Settling time (sec.)	10.44	10.40
Peak overshoot (%)	94.81	94.61
Peak time (sec.)	0.1410	0.1465
Rise time (sec.)	0.0474	0.0494

From the Fig. 2, it is clear that the responses of proposed PI controller and LJ based PI controller are near overlapping. Table II shows that the time domain specifications are also near matching. Hence, it can successfully be concluded that Jaya based PI gives satisfactory results and can be used for tuning the PI controller for double tank system.

CONCLUSION

This contribution proposes Jaya based PI controller for level control of double tank system. The ISE of step input is considered for tuning the PI controller parameters. The ISE is minimized using recently proposed optimization technique namely, Jaya. From simulation study, it is clear that Jaya based tuning of PI controller for double tank system gives satisfactory results.

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