Optimizing the Response of a PID Controller for Three Tank Liquid Level System using Multiobjective Genetic Algorithm

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***Abstract*— This paper proposes the application of multi-objective genetic algorithm for optimizing the response of the PID controller for a three tank liquid level system. Liquid level system is a large-lag, time varying and non-linear system and finds a wide application in food processing, iron and steel, industrial chemical processing and other industries and the quality of control directly affects the quality of products and safety of equipments. Optimizing the response helps in maintaining the level set point at certain desired and be able to accept new set points dynamically. By optimizing the PID controller and comparing the results obtained by conventional methods like Ziegler-Nichols; multi-objective genetic algorithm has a vanguard advantage in satisfying the performance criterion.**

Keywords*— *PID Controllers, Controller Tuning, Multi-Objective Genetic Algorithm , Ziegler-Nichols, Three Tank Liquid Level System.

I. Introduction

Three tank liquid level system control is central to several diverse areas ranging from petroleum, waste water neutralization, industrial chemical processing, boilers, food processing industry etc. to nuclear power generation. Liquid level control for water tank is large lag, time varying and non-linear complex system and the main objective of the control system is to fill the tank as quickly and smoothly as possible.

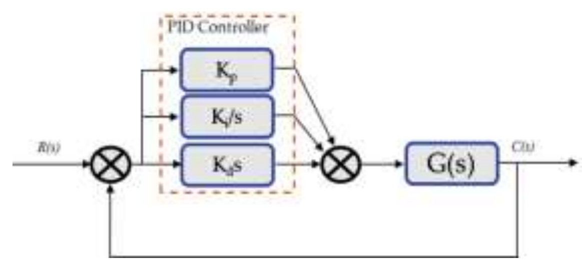
In this paper, a three container water tank is considered, which is generally connected through three first order non-periodic inertial links in series as shown in Figure 2. The controller designing primarily focuses either on the maintained liquid level at a desired set-point, disturbance rejection or to be used for moving the liquid set-point. For designing the controller, a PID- Proportional, Integral and derivative controller is used and the optimization of the PID controller gains has been carried out using Multi-objective Genetic Algorithms (GA) in contrast to the Ziegler-Nichols (ZN) method. While the gains obtained by the help of Ziegler-Nichols, have been used for the determination of the lower and upper bound limits for the initial populations for the optimization.

Then, these gain parameters can be optimally tuned with respect to the objective function, stated as "Sum of the integral of the squared error and the squared controller output deviated from its steady-state" [3].

According to the results obtained in this paper, considerably better results have been obtained in the case of the Multi-objective Genetic Algorithm (GA) when compared to those obtained by Ziegler-Nichols method in their respective step response on the system.

II. PID Controllers

PID- Proportional, Integral, and Derivative controllers because of their simplicity and wide acceptability are playing an imperative role in process control and are still the best solutions for the industrial control processes [4]. Modern industrial controls are often required to regulate the closed-loop response of a system and PID controller's credit for the 90% of the total controllers used in the industrial automation.



A PID controller based system is represented in simple block level diagram as in Fig. 1.

Figure 1. Schematic representation of unity feedback PID controller system architecture.

The general equation for a PID controller for the above figure can be given as [5]:

$$C(s) = K_p.R(s) + K_i \int R(s)dt + K_d \frac{dR(s)}{dt}$$

Where K_p, K_i and K_d are the controller gains, *C(s)* is output signal, *R(s)* is the difference between the desired output and output obtained.

Some of the prime methods for tuning are: Mathematical criteria, Cohen-Coon Method, Trail and Error Method, Ziegler-Nichols Method and now a days the Soft-Computing techniques, being lesser prone to error when compared to conventional methods; like Fuzzy Logic, Genetic Algorithms, Particle Swarm Optimization, Neuro-Fuzzy, Steel Annealing and Artificial Neural Networks, are also becoming dominant in research methodologies.

III. Mathematical Model of a Three Tank Liquid Level System

In this paper, the liquid level control system consists of containers connected by three first-order non periodic inertia links in series and the system can be represented as in Fig. 2

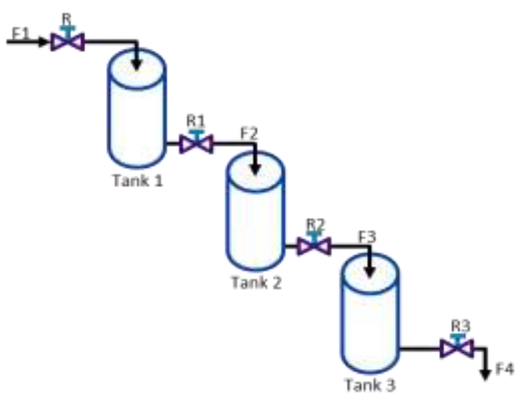


Figure 2. Schematic representation of a three tank liquid level system.

For the tank system, representative above, we get:

$$F_i(t) - F_{i+1}(t) = X_i \frac{dh_i}{dt}$$

Where $F_i(t)$ is tank 1 inflowing liquid (m^3/s), $F_{i+1}(t)$ is tank 1 outflowing liquid (m^3/s), X_i is area of tank and h_i is liquid level in tank and *i*= [1,2,3].

Hence we obtain the four equations of the flow of liquid in all the tanks.

And $F_i(t)=h_i/R_i$

where R_i is linear resistance of tanks.

Thus over all transfer function of the three tank system is

$$\frac{H_3(s)}{F_1(s)} = \left(\frac{R_1}{X_1R_1.s+1}\right)\left(\frac{R_2/R_1}{X_2R_2.s+1}\right)\left(\frac{R_3/R_2}{X_3R_3.s+1}\right)$$

Considering,

$X_1 = X_2 = 1.5m^2$; $X_3=1m^2$

and R1 $= R_2 = 2(m/(m^3/s))$; $R_3 = 3(m/(m^3/s))$

and using them in above equation, we get the transfer function as;

$$G(s) = \left(\frac{3}{27.s^3 + 27.s^2 + 9.s + 1}\right)$$

And the transfer function of the valve $R = \left(\frac{0.133}{3.s+1}\right)$

IV. Designing of the PID Controllers

A. *Designing by Ziegler-Nichols Method*

One of the most widely used method for the tuning of the PID controller gains is to use the open loop response as inferred by Ziegler-Nichols(ZN), yet this method finds its in application till the ratio of 4:1 for the first two peaks in the closed loop response[3], which leads to a oscillatory response of the system.

Initially, the unit step function (Fig. 3) is derived, and hence as suggested by the Ziegler-Nichols, the parameters required can easily be estimated as given in Table 1.

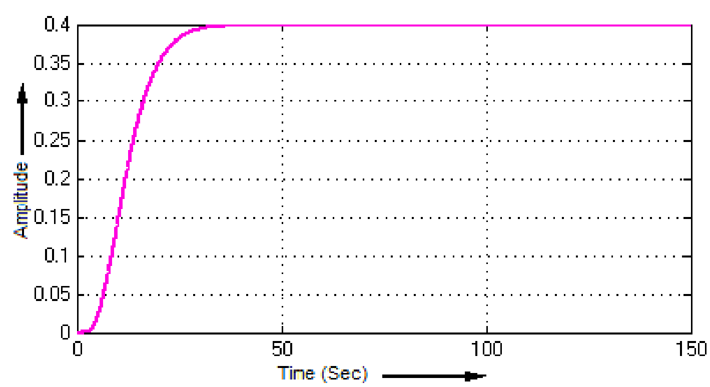


Figure 3. Open loop step response of the three tank liquid level system.

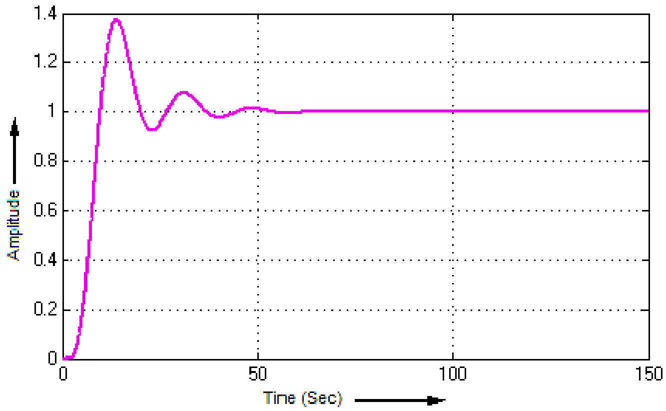


Figure 4. Closed loop response of the Ziegler-Nichols PID Controller for the three tank liquid level system.

TABLE I. ZIEGLER-NICHOLS PARAMETERS OF THE PID CONTROLLER

PID Controller Parameters	***Value***
Kp	7.4383
Ki	0.7158
Kd	18.9753

B. *Multi-objective Optimization using Genetic Algorithm.*

Since, an oscillatory response is obtained while designing the PID controllers by Ziegler-Nichols methods; hence the controller parameters obtained from ZN are not optimum for the directly implementation for the plant, so their organized optimization must be carried out, that the better possible parameters can be estimated and implemented for the best performance of the system.

Optimization of PID’s using multi-objective genetic algorithm aims at using the controlled elitist genetic algorithm which boosts obtaining the better fitness value of the individuals and if the fitness value is less, it still favors increasing the diversity of the population [6]. Diversity is controlled by the elite members of the population; elitism is controlled by Pareto fraction and at Pareto Front also bound the number of individuals. The parameter determined by ZN helps in the determination of the initial lower and upper bound limits to be used for the optimization, and focuses on minimizing the integral square error.

The system implementation and optimization has been carried out in Matlab and Simulink environment using Global Optimization Toolbox. The population size of 45 has been considered, with adaptive feasible mutation function and the selection of individuals on the basis of tournament with a tournament size of 2. After the optimization the PID parameters are shown in Table 2 along with the controller response in figure 5.

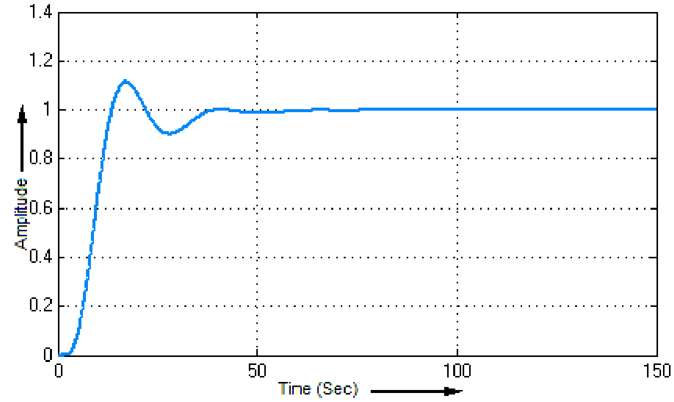


Figure 5. Closed loop response of the Multi-objective Genetic Algorithm tuned PID Controller for the three tank liquid level system.

TABLE II. MULTI-OBJECTIVE GENETIC ALGORITHM PARAMETERS OF THE PID CONTROLLER

PID Controller Parameters	***Value***
Kp	4.1959
Ki	0.2977
Kd	7.0289

V. Results and Discussions

In this paper, a dynamic model of a three tank liquid level system has been designed and implemented in MATLAB along with the optimization using the Multi-objective Genetic Algorithms. The parameters obtained by using Ziegler-Nichols rules[10] are used in the formation of the initial boundary limits for the intervals for the design parameters in Multi-objective Genetic Algorithms, to control the controller by minimizing the error, and hence the determination of the optimum parameters for the plant.

The computation of the gain parameters are done by the Ziegler-Nichols rules and the Multi-objective Genetic Algorithms. It is clearly evident in Fig. 6 that the Genetic Algorithms solutions present a less oscillatory response in contrast to the Ziegler-Nichols. The results have been presented in Table 5. Concluding, Multi-objective Genetic Algorithms offers superior results in terms of system performance for the tuning of PID controllers when the values are compared in Table 3 and Figure 6.

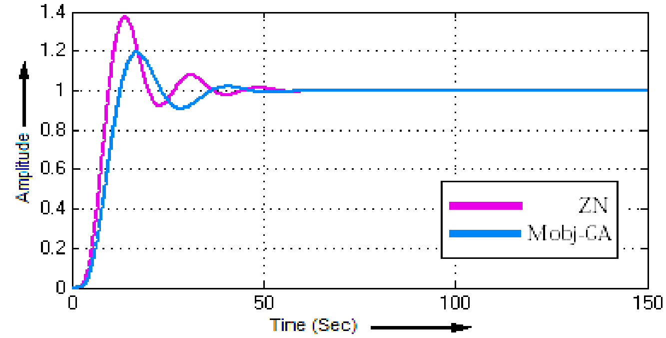


Figure 6. Closed loop response of the Ziegler-Nichols PID Controller for the three tank liquid level system.

TABLE III. COMPARISON OF THE RESULTS

Method of Design	***Overshoot %age***	***Rise Time***	***Settling Time***
Ziegler Nichols	37.2	4.8 sec	48.5 sec
MultiObjective GA	11.3	6.0 sec	36.1 sec

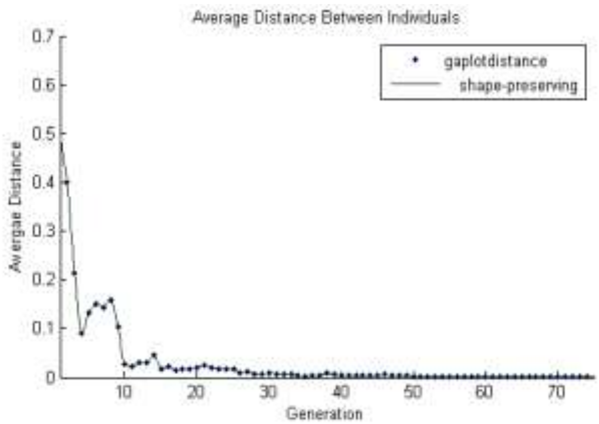


Figure 7. Average distance between individuals of the generated populations

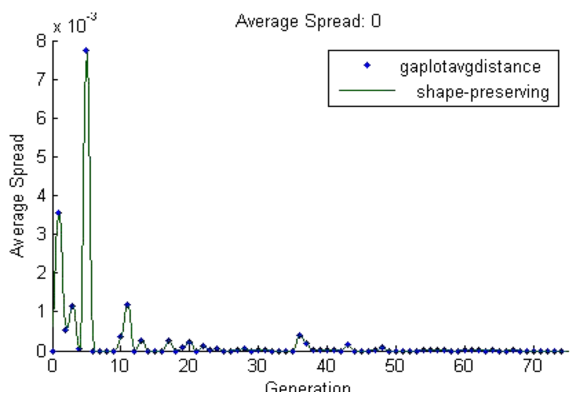


Figure 8. Average Pareto spread between individuals of the generated populations.

VI. Conclusion

The use of Multi-objective Genetic Algorithms for optimizing the PID controller parameters for the three tank liquid level system as presented in this paper offers advantages of decreased overshoot percentage, and settling times yet rise time is better in case of Ziegler-Nichols as shown in Table 3. The response of controller obtained after optimization offers a lesser oscillatory response when compared to conventional method and so promises a better and smooth operation of the system. Results when compared with the conventional tuning parameters, the Genetic Algorithms have proved superior in achieving the steady-state response and performance indices.

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