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Genetic Algorithm Utilization to Fine Tune the Parameters of PID Controller

Ghaith Majd Fadhil[1], Issa Ahmed Abed[2,*], and Rasheed Sabah Jasim[3]

[1,2,3] Engineering Technical College, Southern Technical University, Basrah, Iraq

***Corresponding authors email: issaahmedabed@stu.edu.iq**

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ABSTRACT

In this paper, the genetic algorithm (GA) which is a stochastic optimization algorithm is proposed. The genetic algorithm is echoing the natural selection and genetics. The control of the suggested plant can be done in different ways. Genetics are used to solve the problem that will be in the system that is represented by the response, ripple, and overshoot. Here, the proportional, integral, and derivative (PID) controller is used. The $K_{p,}$, K_i , and K_d of PID are controlled using a genetic algorithm. Then the procedures of GA are given which are implemented in Matlab 2018a. Also, the output response is compared with the set value to check the ability of GA to get the optimal solution. Through simulated results, there is a high response to the system, as well as the ripple, and the overshoot decreased significantly compared to the conventional method in control.

KEYWORDS: PID; Optimization; Plant; Genetic algorithm

1. INTRODUCTION

The proposed controller is considered as the sum of three controllers which are proportional, derivative, and integral, therefore it is called (PID). PID is widely used in many applications (Odhafa et al., 2020) because of its simple structure and accurate results. It is used in many industrial applications (Koivo and Tanttu, 1991; Åström and Hägglund, 2001; Yamamoto, 1991). The control structure using the PID controller is shown in Fig. 1.

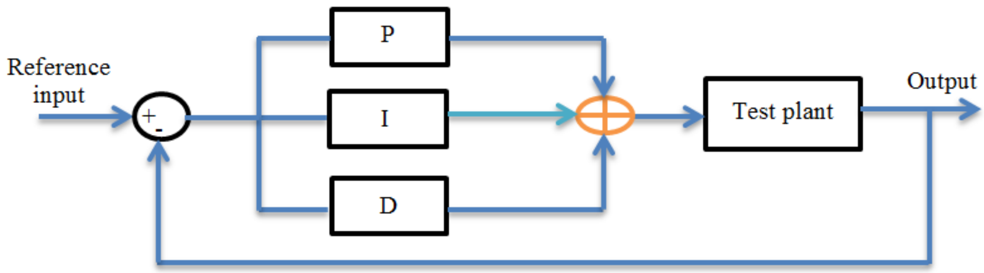

Fig. 1. Control system structure.

PID controller is used to controlling the framework and reduce error. In this closed-loop system, the sensing signal will compare with the setpoint which is defined initially. Then the difference signal goes to the PID controller to control the plant. Hence, the PID representation is presented in equation 1.

$$\mathrm{PID}(s) = K_P + \frac{1}{s} K_I + s\, K_d \tag{1}$$

Where $\mathrm{PID}(s)$ is the transfer function. The use of proportional and then adds an integral part in order to reduce the error and getting a more stable system. But when the derivative is incorporated in the controller, then the error will be less influence than using p- action, and I-action. In the classical system, it can use the PID, whose parameters are changed manually. In the event of any change in the system, it cannot give the same response. Therefore, the genetic algorithm was introduced for this purpose. The results in this paper are compared with the results of the paper in the indicated source (Tandon and R. Kaur, 2011). From it, we conclude that the best results were obtained through the response and overshoot of the work from this paper. The PID controller is used with different test plants to show the response of the system as well as to solve the problem in the response system.

In this work, the PID controller is used to adjust the system to produce optimal output response. In that case, the parameters of PID should be arranged. Different classical methods have been used to tune the controller (D'Azzo and Houpis, 1988; Levine, 2000; Åström and Wittemark, 1993). Recently, optimization techniques are utilized to find the best parameters for PID. The genetic algorithm (GA) is a metaheuristic method which is derived from natural selection principles, the details of this algorithm are introduced in the following section (Abed et al., 2013). This paper is used to solve the problem of system response such as ripple and overshoot.

2. CLASSICAL METHOD TO CONTROL THE PID CONTROLLER

In the traditional PID control, the controller is updated through the manually changing in its parameters. This method causes a lot of problems and it is difficult to guess a suitable set of parameter values that help to give acceptable output for the system, so you need a PID that fits the system in each change. Fig. 2 shows the traditional control method.

Fig. 2. Classical method to control the test plant.

3. GENETIC ALGORITHMS

The genetic algorithm (Mostafa, 2013) provides an adaptive searching mechanism inspired by Darwin's principle of reproduction and survival of the fittest. The individuals (solutions) in a population are represented by chromosomes; each of them is associated with a fitness value (problem evaluation) (Wdowiak, 2017; Ghasemi, 2017). The chromosomes are subjected to an evolutionary process that takes several cycles (Magzoub, 2013; Selvi and Gopinath, (2015). The basic operations of GA are selection, reproduction, crossover, and mutation (Cunkasa and Akkaya, 2006). Parent selection gives more reproductive chances to the fittest individuals. During crossover, some reproduced individuals cross and exchange their genetic characteristics. Mutations may occur in a small percentage and cause a random change in the genetic material, thus contributing to introduce variety in the population. The mutation used to avoid the chromosomes lie in local minima during the evolutionary process (Rahman et al., 2013). This search will recognize the parameters of the system and makes those system stable (Zhang and Naghdy, 1995). The complete flow chart is given in Fig. 3. The evolution process guides the genetic algorithm through more promising regions in the search space (Odofin et al., 2016; Maitre et al., 2015). The advantages of using a genetic algorithm are: it is a global search technique, can be applied to the optimization of ill-structured problems, and doesn’t require a precise mathematical formulation for the problem. Besides, a genetic algorithm is robust, applicable to some problems, and efficient, in the sense that either a suboptimal or optimal solution may be found within a reasonable time.

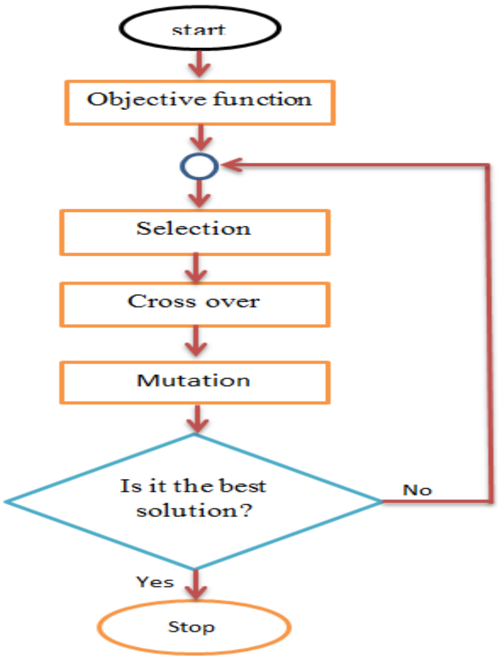

Fig. 3. Flowchart of a genetic algorithm.

4. PROPOSED GENETIC ALGORITHM WITH PID CONTROL

Here, an auto-tuning of the PID controller is displayed. The overall system is shown in Fig. 4. Where the genetic algorithm is incorporated with the PID controller to control this system. The control is performed by tuning the PID parameters through the algorithm where the values of the controller are arranged according to the operation of the system. A Genetic are utilized to inspire an objective function that can estimate the parameters of the PID controller based on the controlled system's overall error. According to the objective function, the parameter of the PID controller is suggested.

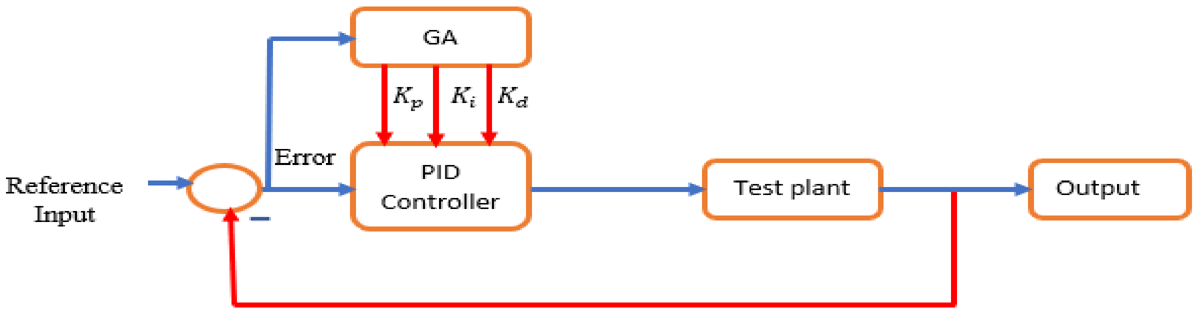

Fig. 4. Control the plant using a genetic algorithm.

As a result, the suggested PID controller provides the smallest overshoot, quickest rising time, and very accepting of settling time. The genetic algorithm has been implemented to control the parameters of PID for any transfer functions. The genetic algorithm will select the best parameters and this will help to reduce the ripple and enhance the specifications of the response. When the optimization is done with PID, the following procedures should be done.

4.1 Initial Population

The limits of K_p, K_i and K_d are between 0 and 300. While the population size which is selected in this work is about 25.

4.2 Objective Function

The objective function is a mathematical expression that describes the relationship of optimization parameters or the result of an operation that utilizes as input to the optimization algorithm. The objective function can be calculated as (Odofin et al., 2016):

$$\mathrm{ITAE} = \int_0^T t|e_t|\, dt \tag{3}$$

ITAE: integral of time multiply by absolute error

e_t : the error signal of time

Where the genetic operators that tune PID parameters are dependent on the error which is reduced with the increase of the number of generations.

4.3 Selection

Individual selection is random which depends on the Roulette wheel selection method to choose the desired individual. When the $p_s > p_r$, p_s the selection probable

$$\text{Probable of selection} = \frac{\text{Objective i}}{\sum_i^n \text{Objective i}} \tag{4}$$

Where p_r is a random probability with a range between [0-1].

4.4 Crossover

This operator produces new chromosomes to which have different values of fitness to compare and get new chromosomes according to crossover probability (p_c) which is a random value between [0-1] and the p_c sometimes is 0.8. When $p_c > p_r$, the cross over will happen.

4.5 Mutation

The mutation is made by comparison random number between [0-1] with the mutation probability (p_m), where p_m is mostly 0.08 and random probability (p_r) value range between [0-1]. When $p_r \leq p_m$ then the mutation will happen.

5. SIMULATION RESULTS

The results are performed with Intel Core i7 CPU and 8 GB PC. All the simulations have been done using Matlab 2018a. The maximum generation is 20 and the crossover probability is 0.6. The complete simulation of the system is shown in Fig. 5 where the system will determine the error after the tune of the PID parameters according to the genetic algorithm optimization, the PID is connected in series with the test function. The parameters setting of genetics as shown in Table 1.

Table 1. The parameters setting of GA.

Parameters	Magnitude
Selection	Roulette wheel
Population Size	25
Cross Over Probability	0.8
Mutation Probability	0.08
Ranges of PID	0-300
No of iteration	25

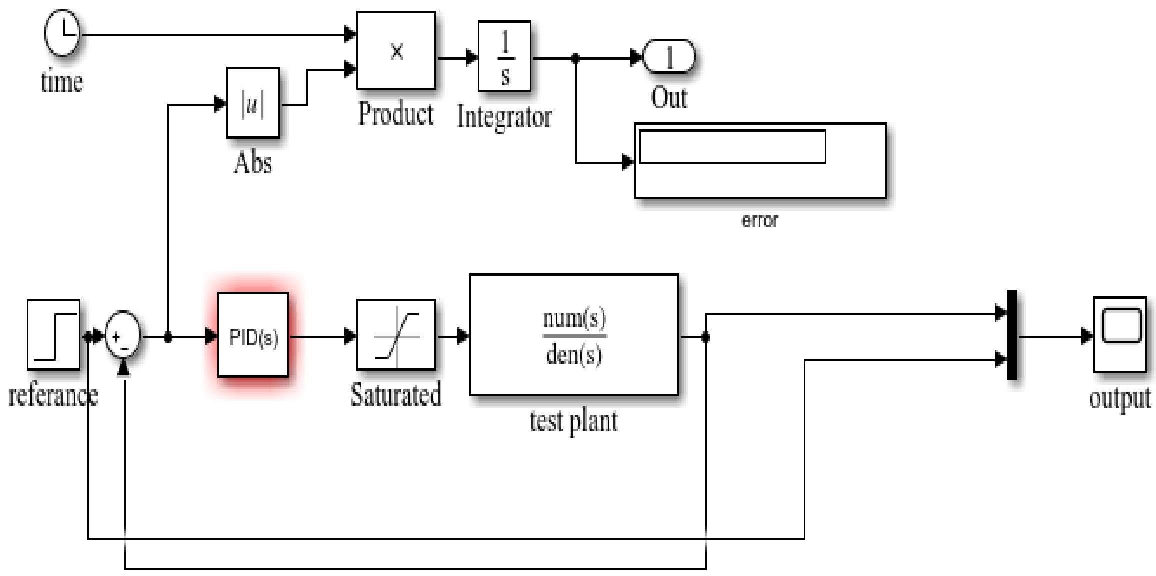

Fig. 5. Simulink model of a system with GA.

Different cases have been utilized in this paper.

First case study

In this case, the proposed plant is

$$\text{Test plant 1} = \frac{S+2}{S^4+8S^3+4S^2-S+0.4}$$

Fig. 6 shows the response of this test and the reference signal is unity. The fourth-order test plant is tested with the number of iterations 25 as well as the population size 25.

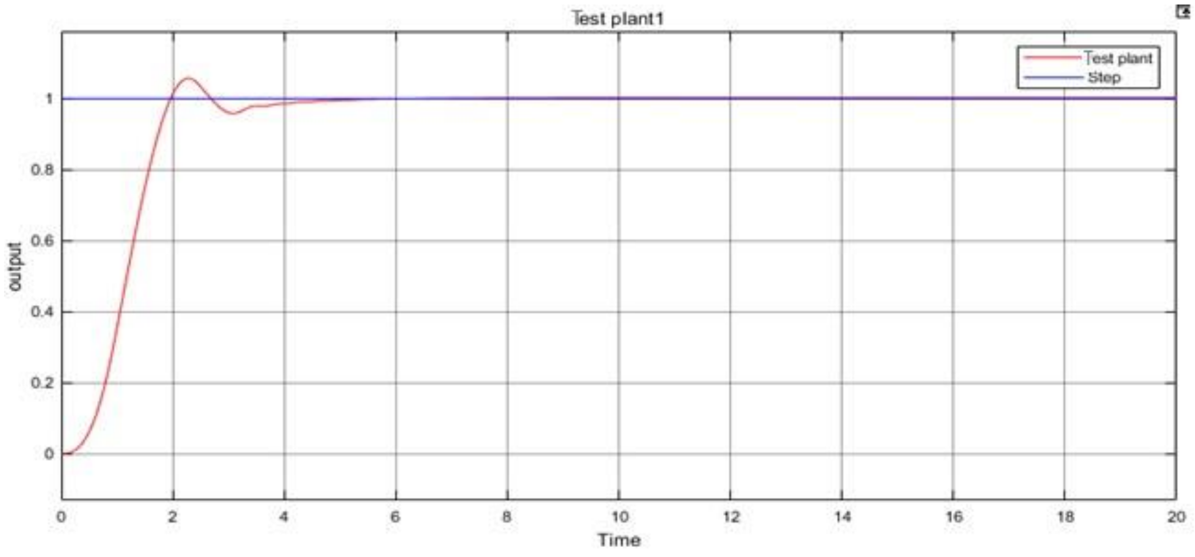

Fig. 6. The response of the system with test plant 1 using GA.

Second case study

The function of the system is

$$\text{Test plant } 2 = \frac{S+8}{2S^3+5S^2+7S+9}$$

The response and the reference signal is unity is presented in Fig. 7, where the response reaches the steady-state before the 6 seconds. The third order test plant is tested with same the number of iterations 25 as well as the population size 25.

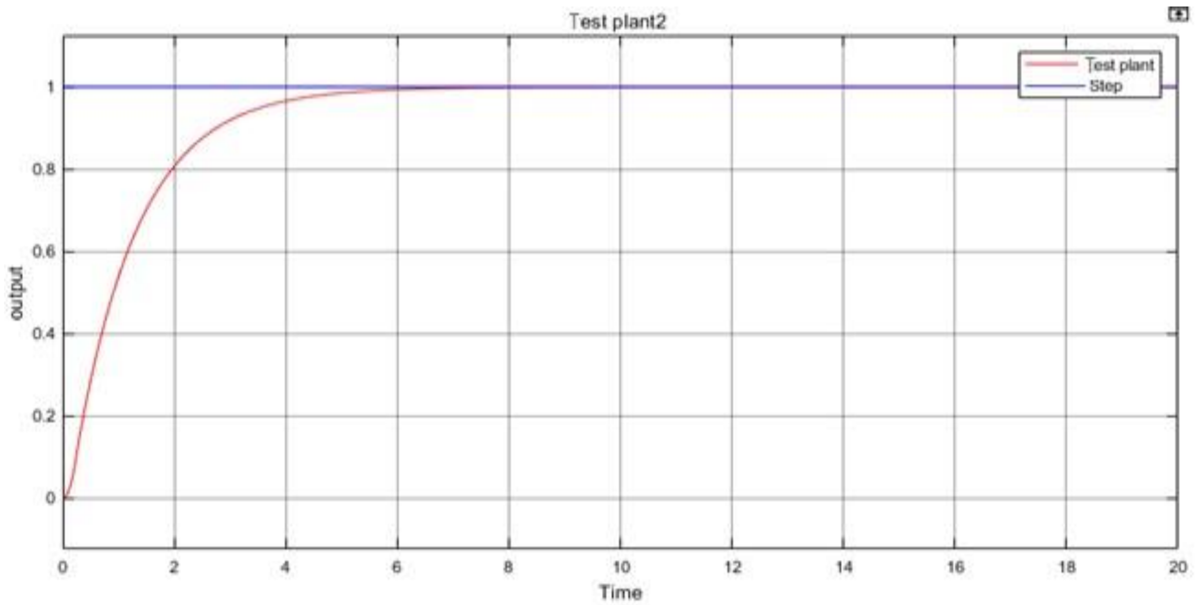

Fig. 7. Response of system with test plant 2 using GA.

Third case study

The function is

$$\text{Test plant 3} = \frac{S+3}{S^3+2S^2+12S+9}$$

However, the response of this function and the reference signal is unity is given in Fig. 8. The third order test plant is tested with same the number of iterations 25 as well as the population size 25.

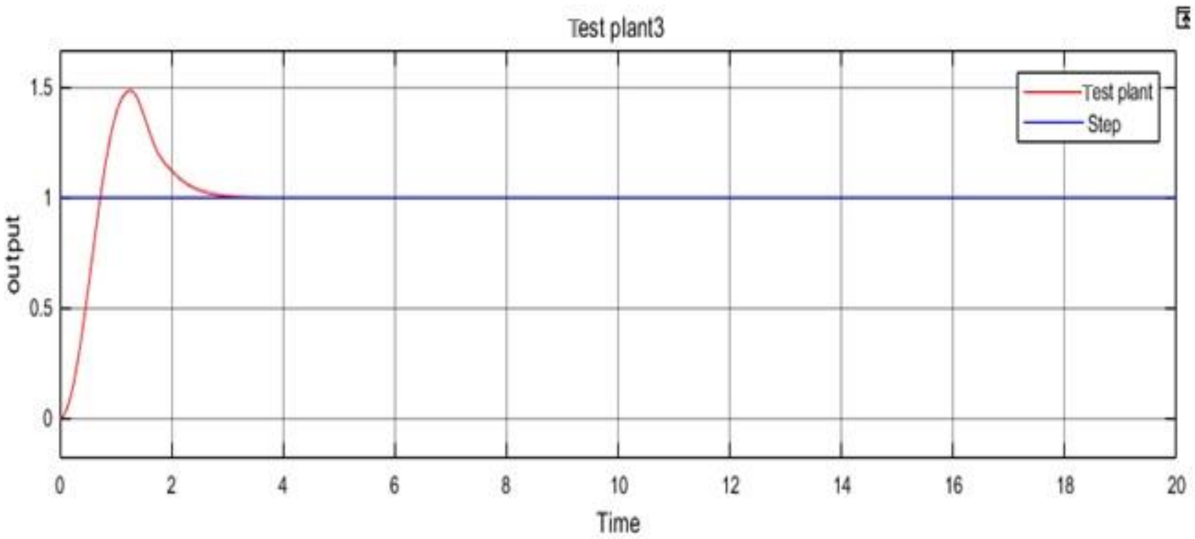

Fig. 8. Response of system with test plant 3 using GA.

Table 2 shows the optimal values for each set of PID parameters as well as the objective value, where the third test is less objective value compare to the others.

Table 2. The optimal values of objective function and PID parameters.

	Test function	K_p	K_i	K_d	Objective value
1	Test plant 1	256.8107	0.6934	289.7176	1.05466
2	Test plant 2	238.06	0.640267	269.5504	1.0671
3	Test plant 3	198.9107	28.46	30.322944	0.8611

In all tests, the GA helps the output to follow the desired response in an acceptable time which means that the proposed GA is very suitable for this job. The comparted by the objective function on the three test plants as shown in Fig. 9.

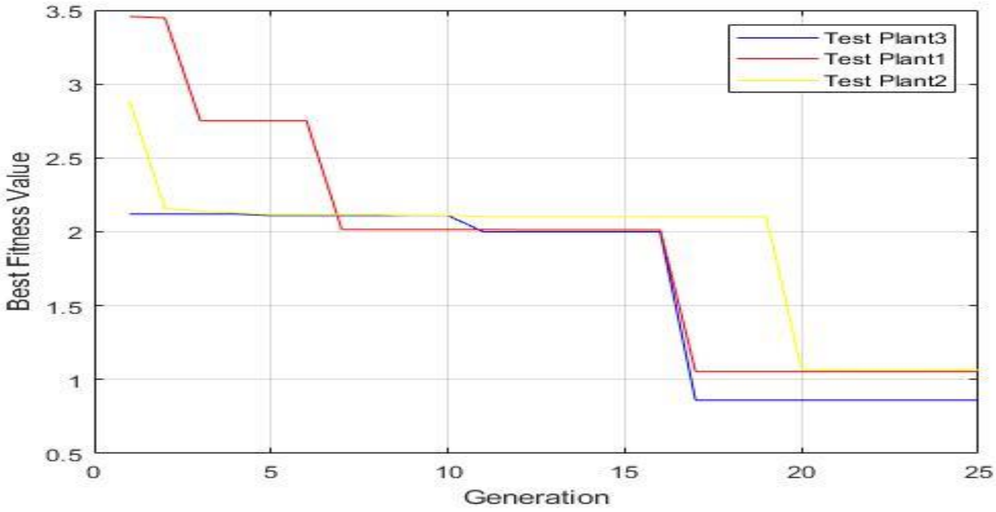

Fig. 10. Comparisons of Objective Function between Three Test Plants.

In order to prove the ability of GA and in the case of test plant 3, the two controllers are compared which are without control, traditional-PID, and GA- PID from which results were obtained according to a Table 3. In this paper, there will be an ideal global solution and its comparison through objective function. Therefore, the system's work with the genetic algorithm was accurate and more responsive compared to the traditional method as shown in Fig. 10.

Table 3. Comparison of Test plant 3 response between traditional-PID and GA-PID control.

Parameters	Without Control	Traditional control	GA control
Over shoot	55.754%	27.56%	0%
Error	2	1.2	0.074
K_p	-	150	198.9107
K_i	-	20	28.46
K_d	-	15	30.322944

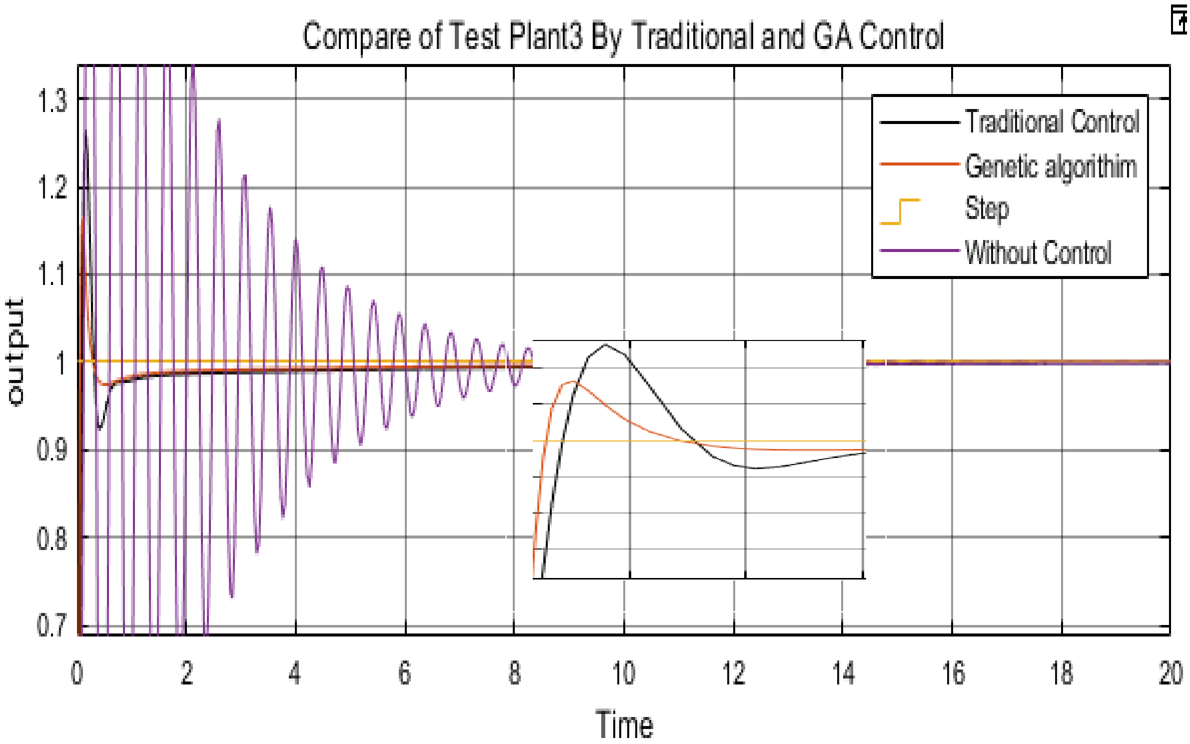

Fig. 10. Comparisons between traditional-PID method and GA-PID.

6. CONCLUSION

The genetic algorithm is proved to be a good optimization algorithm in many applications and it is outperformed many algorithms in the literature. In this work, one structure of a genetic algorithm is proposed to tune the parameters of the PID controller for different processes. Where the GA has been utilized to fine-tune the PID parameters and obtains the best solution. The results demonstrated that the genetic algorithm can find the optimal solution and reduces the error between the set signal and the system response.

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