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Comparison between Genetic Algorithm and Simulated Annealing Technique of Lag-Lead Compensator

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Abstract - The Proportional-Integral-Derivative controller's area unit the foremost unremarkably used controllers in industrial applications. As is acknowledge, the Proportional-Integral-Derivative controller's area is unit at risk of noise interference and windup impact. A lot of sensible alternatives are lead-lag compensators. Generally, frequency-division or time-division strategies area unit used to design a lead-lag controller to meet the design stipulation. The main task of this text is to form a needed lead-lag controller mistreatment genetic algorithms (GAs). A main feature of our approach is to incorporate the look specifications directly into the cost function or fitness function perform in GA iterations. Computer unit simulations show that the performances of our planned controllers unit quite desirable.

Keywords — Genetic algorithm, Lag-lead compensators, P-I-D controller, cost perform, fitness perform.

I. INTRODUCTION

PID (Proportional-Integral-Derivative) controllers are practicably the most commonly used controller in technical purposes. Quite a few typical techniques are proffered for attune the PID controller criterion over the period [1-3]. PID controllers are susceptible to high frequency noise interference and windup (integrator windup) effect [4-8].

The tuning of the three design parameters, namely- K_P , K_I and K_D very often depends on expertise action, subject-matter theory, or an effort and error procedure. More practical alternatives are lead-lag controllers, where we have 5 design parameters [9-10]. The genetic algorithm (GA), basically evolved by John Holland over the course of the 1960s and 1970s, is a biologically actuated search technique mimicking natural action and natural biology [11-13]. It is applied to attune the PID controller criterion [14-17]. This paper is focused on the design of the lead-lag controllers to meet the design stipulation. The design of the lead-lag controllers has been studied in [18-20].

Nevertheless, to the best of the author's knowledge, the lead-lag compensator design based on genetic algorithms is not often quoted so far [21-22]. Tuning the lead-lag controller based on Integral Absolute-Error (IAE), Integral Square-Error (ISE), and Integral of Time-Weighted- Squared-Error (ITSE) was proffered in [21]. Designing lead- lag controllers or second-order controllers by using a combined fitness function was presented in [22]. The main difference of our current approach proffered and those in [21] and [22] is that the design specifications on peak time, overshoot, undershoot, and steady-state error are directly included into the cost perform or fitness perform in GA iterations.

II. TIME-DOMAIN SPECIFICATIONS

It is well known that in simple second-order under- damped systems, the design specification is usually expressed in terms of peak time, percentage overshot, setting time, rise time, and steady-state error of the step response [9-10]. For a general system, our design specifications will be expressed in the following terms; see Fig. 1. Let $y(t)$ be the unit-step response. Let y_{os} denote the first overshoot, y_{us} the first undershoot, and y_{ss} the steady-state value of $y(t)$. The peak time T_p is first time to reach y_{os}.

The percentage first overshoot OS is defined as

$$OS = \begin{cases} 0, & y_{os} \le y_{ss} , \\ \frac{(y_{os} - y_{ss})}{y_{ss}}, & otherwise \end{cases}$$

The percentage first undershoot US is defined as

$$US = \begin{cases} 0, & y_{os} \le y_{us} , \\ \frac{(y_{ss} - y_{us})}{y_{ss}}, & otherwise \end{cases}$$

The steady-state error E_{ss} is the difference between the unit reference input and the final steady-state response value. In this study, the control specifications are given in terms of the peak- time T_p , first overshoot OS, first undershoot US, and steady-state error E_{ss}. For instance, control design specifications are given as follows:

$$1.95 \le T_p \le 2.05 , 0 \le OS \le 0.03 , 0 \le US \le 0.02 , 0 \le E_{ss} \le 0.01$$

The goal is to find a lead-lag compensator that meets all the specifications. If this cannot be done, we should try to find one that produces the response as close as possible to the specification.

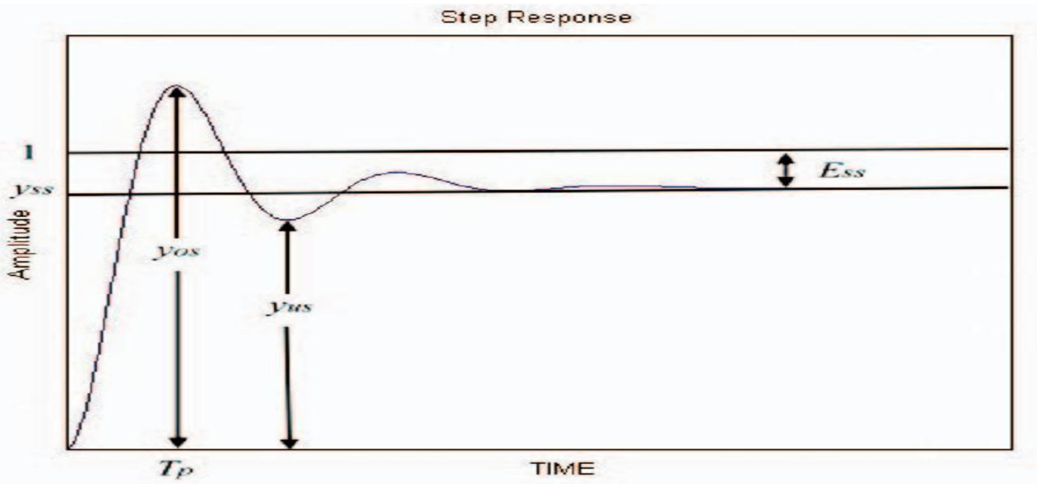

Fig.1:- Typical unit-step response

III. LEAD-LAG COMPENSATOR

Lag-lead compensators can improve the performance of linear control systems through the proper tuning of the compensator parameters. There are two establishments in designing lag-lead compensators. One of them uses the frequency response specifications of the compensated control system. The other uses its time response specifications. In the present work we follow the research school using the time response specifications. Still the substrate is interested to automatic control researchers. The transfer perform of a lead-lag (or lag-lead) controller may be written as

$$G_c(s) = K\left|\left(\frac{T_1 s + 1}{\alpha T_1 s + 1}\right)\cdot\left(\frac{T_2 s + 1}{\beta T_2 s + 1}\right)\right|, K > 0 , \alpha > 1 , 0 < \beta < 1 \quad (1)$$

$$D_{LEAD}(S) = K\frac{T_s + 1}{\alpha T_s + 1};\quad \alpha < 1 \quad (2)$$

$$D_{PD}(S) = K(T_D s + 1) \quad (3)$$

$$D_{LAG}(S) = K\frac{T_s + 1}{\alpha T_s + 1};\quad \alpha > 1 \quad (4)$$

$$D_{PI}(S) = K\frac{T_1 s + 1}{T_1 s} \quad (5)$$

Because the lead-lag controller in Equation (1) now has five unknown parameters, its design is not as straightforward. As a general rule, the phase-lead part of the controller is used primarily to attain a shorter peak time and higher bandwidth, and the phase-lag part is used to provide damping of the system.

The Lead compensator given in Eq. 2 is a better version of the PD (Proportion Derivative) controller given in Eq. 3. According to Eq. 2, the Lead compensator is a PD controller combined with a low pass filter. One advantage of this low pass filter is the damping of unnecessary high frequency noise picked up by the plant and the sensors that cause control problems and reduced lifetime of plant actuators. The name “Lead compensator” is given because it improves (leads) the phase margin of the plant thereby improving stability and transient response of the closed loop system.

Where, K, α, T, T_D and T_I are parameters need to be designed and **s** is the Laplace variable. The Lag compensator given in Eq. 4 is a better version of the PI (Proportional Integral) controller given in Eq. 5. The PI and Lag compensators help to increase steady state gain of the plant to reduce steady state error. The drawbacks of PI and Lag compensators are the reduction of phase margin that degrades transient responses of the closed loop system.

The PI controller reduces the phase for all the frequencies less than $1/T_I$ rad/sec whereas the Lag compensator reduces phase only for a small range of frequencies around $1/T_I$ radians per second. Therefore, it is advantages to use a Lead compensator instead of PI controller. Accordingly, the Lead/Lag compensator that combines both Lead and Lag compensators is clearly, a better version of the PID controller.

IV. GENETIC ALGORITHMS

A GA, as proposed by J. Holland in 1995, is a stochastic optimization technique imitating the natural selection process in biological evolution. GAs is commonly used to solve optimization problems. The algorithm is started with a set of solutions (represented by chromosomes) called the population. Solutions from one population, which have a high fitness, are “selected” to survive.

New solutions (offspring) are created from the surviving solutions by “crossover” and “mutation”. In this way, the cycle of “selection,” “crossover,” and “mutation” evolves the population by repetition. The flow of a GA is shown in Fig. 2.

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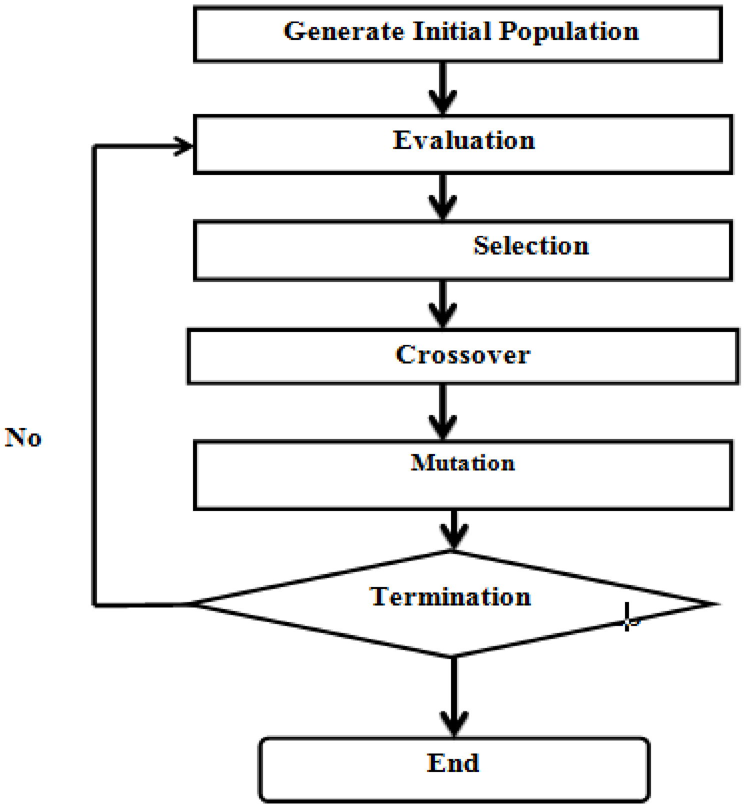

Fig.2:- Flow chart of a GA

V. GENETIC ALGORITHM-BASED OPTIMIZATION

To state the proposed cost function, define

$$f_1(a;b) = \begin{cases} 0, & 0.95 \le a \le 1.05b, \\ |(a-b)/b,| & otherwise, \end{cases}$$

$$f_2(a;b) = \begin{cases} 0, & a \le b, \\ |(a-b)/b,| & otherwise, \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(6)$$

The cost function used in this paper is given by

$$J = w_1 f_1(T_p; DT_p) + w_2 f_2(OS; MOS) + w_3 f_2(US; MUS) + w_4 f_2(E_{ss}; ME_{ss}) \ldots\ldots\ldots\ldots.(6a)$$

$$w_1 + w_2 + w_3 + w_4 = 1 \qquad \ldots\ldots\ldots\ldots.(6b)$$

In the cost function (6), DT_p is the desired peak time, *MOS* is the maximum allowable first overshot, *MUS* is the maximum allowable first undershoot, ME_{ss} is the maximum allowable steady-state error of the step response of the closed-loop system and w_1, w_2, w_3 and w_4 represent weights reflecting the relative importance of the corresponding term. This cost function is to be minimized with respect to all possible design parameters. Notice that we have included in the cost function the design specifications expressed as a function of peak time, overshoot, undershoot, and steady-state error. Moreover, we allow some tolerance in the peak time.

The GA starts by creating a population of N individuals randomly. Each individual is called a chromosome in GA terminology, and it represents a candidate solution to our optimization problem. In many practical applications, the real encoding is used to represent each chromosome. In this encoding scheme, each chromosome is encoded as a vector of real numbers, with length equal to the number of design parameters. In our case of lead-lag compensator, a chromosome is a vector of five real numbers. A population size 50 is implemented in our simulations.

The cost value is evaluated for each individual in the population. Selection is a process of choosing parents and putting them into the mating pool for reproduction. Chromosomes of lower cost values will be selected with higher probability. A commonly used selection method is the fitness-proportionate selection. In this scheme, the selection probability of an individual is proportional to its cost value [12-13-23]. In order to maintain reasonable relative cost value ratings of chromosomes and to prevent a too-rapid takeover by some super individuals, the ranking selection will be used in this study. The idea is simple: Arrange the population from the best to the worst and allocate the selection probability of each individual in proportion to its ranking but not raw cost.

Elitism means that we retain some number of the best chromosomes at each generation and put them directly into the mating pool. In our simulation, the best 2 chromosomes will be put them directly into the mating pool.

The genetic operators of crossover and mutation with some pre-specified probabilities are implemented at this stage that result a few individuals from the mating pool to reproduce. Crossover is a reproduction operator that forms a new chromosome from two parent chromosomes by combing part of the information from each, controlled by a parameter P_c called crossover probability or crossover rate, with the hope to generate better offspring. The assumption here is that only one pair of offspring is generated by the crossover operation of parents. In the study, the linear crossover with probability 0.8 is implemented.

Mutation is a reproduction operator that randomly alters the values of genes in a chromosome, controlled by a parameter P_m called mutation probability or mutation rate, with the hope to escape from the local optima (or leapfrog over the sticking points) of the cost landscape. In this study, a mutation rate 0.02 is implemented.

The GA process is repeated until the termination condition is satisfied. In this study, the process is terminated if the best cost value in the population over generations becomes stable or the pre-specified maximum generation number is reached. The maximum generation number 10,000 is implemented in our simulations.

VI. CASE STUDY

In the following, we provide three numerical examples for unity feedback system [9-10].

Case 1: Suppose the plant transfer function of a type 0 system is given by

$$G_p = \frac{160}{s^2 + 16s + 16}$$

The step response of uncompensated system is shown in Fig. 3. Here, the peak time is 0.249 seconds, the percentage overshot is 13.3%, and the steady-state error is equal to 0.273.

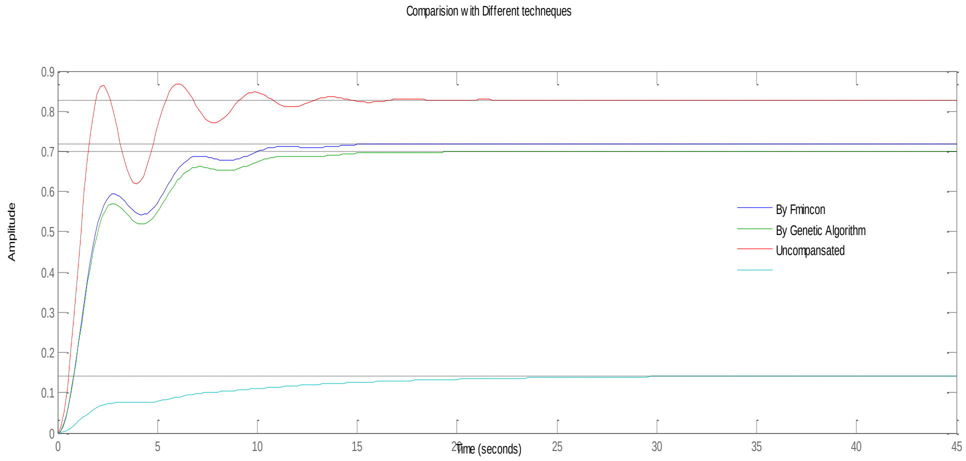

Fig.3:- Step response of the uncompensated system

Suppose our design specifications are given by

$$0.095 \le T_p \le 0.105 \, , 0 \le OS \le 0.03 \, ,$$
$$0 \le US \le 0.02 \, , 0 \le E_{ss} \le 0.01 \, .$$

Clearly, the uncompensated system does not satisfy the design specifications. We may set in equation (2) the following parameters:

$$DT_p = 0.1, \; MOS = 0.03, \; MUS = 0.02, \; ME_{ss} = 0.01, \; w_1 = w_2 = w_3 = w_4 = 1/4$$

See Table.1.for the parameter setting of GA of this example and another two examples. The final parameters for the lag-lead compensator are shown in Table.2. These are also containing those for other examples. The step-response of the compensated system is shown in Fig.4. As shown in Table.3, we have

$$T_p = 0.009621, \; OS = 0.000000, \; US = 0.016473, \; E_{ss} = 0.010217$$

As can be seen, the design stipulations are almost satisfied, except the actual steady-state error is a little bit bigger than desired. The plot of best cost values over generations is shown in Fig.5. This show 200 generations is sufficient for the best cost values in the population over generations to become stable.

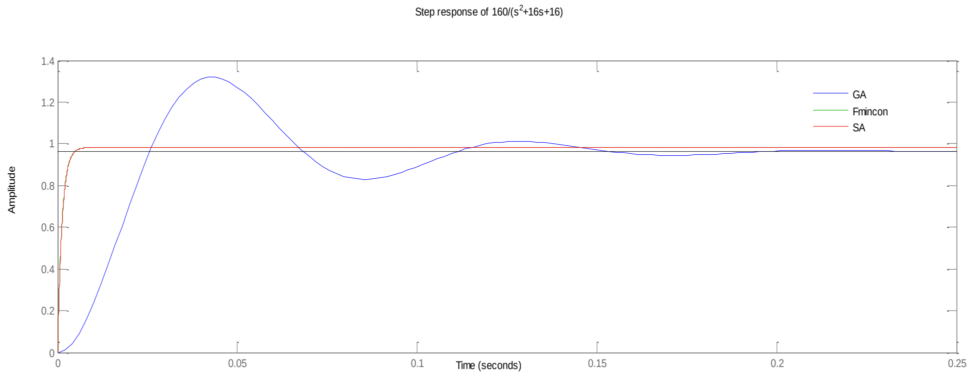

Fig.4:- Step response of the compensated system

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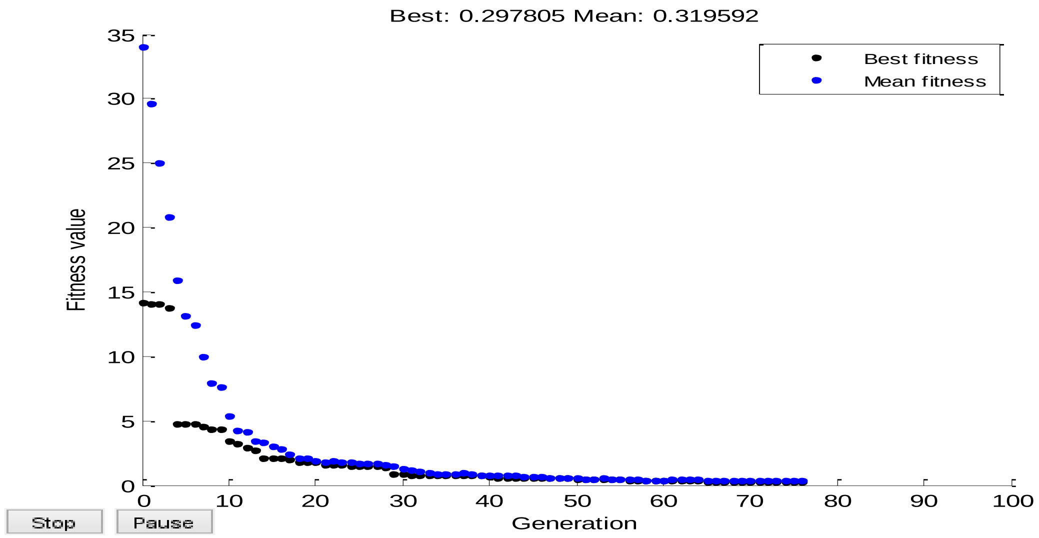

Fig.5:- Best cost values over generations.

Case 2: Suppose the plant transfer function of a system is given by

$$G_p(s) = \frac{700}{(s+2)(s+4)(s+6)}$$

The uncompensated system is unstable. The step response of uncompensated system is shown in Fig.6.

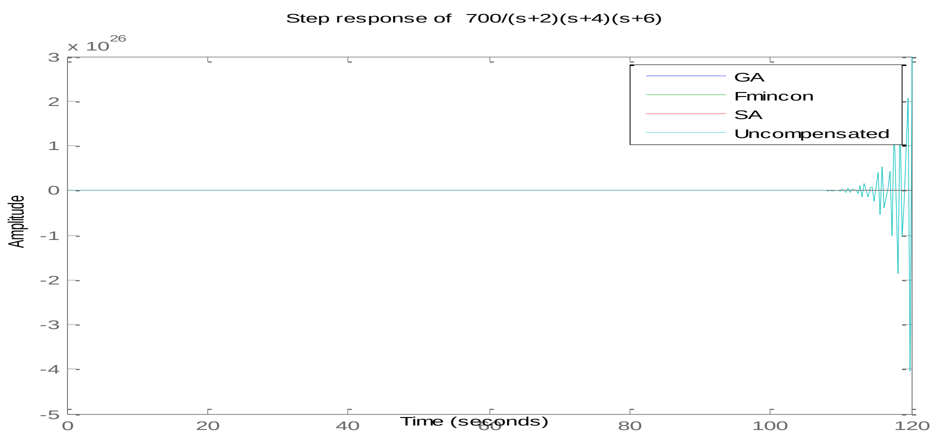

Fig.6:- Step response of the uncompensated system

Suppose our design specifications are given by

$0.57 \le T_p \le 0.63$,$0 \le OS \le 0.03$, $0 \le US \le 0.02$,$0 \le E_{ss} \le 0.01$.

We may set in equation (2) the following parameters:

DT_p = 0.6, MOS =0.03, MUS = 0.02, ME_{ss}=0.01, w_1=w_2=w_3=w_4=1/4

The unit-step response of the compensated system is shown in Fig. 6. As shown in Table.3, we have

T_p= 0.675675, OS= 0.019114, US=0.019891, E_{ss}=0.009998

As can be seen, the design stipulations are almost satisfied. The plot of best cost values over generations is shown in Fig.7. This show the best cost values in the population over generations converge very fast to a stable value.

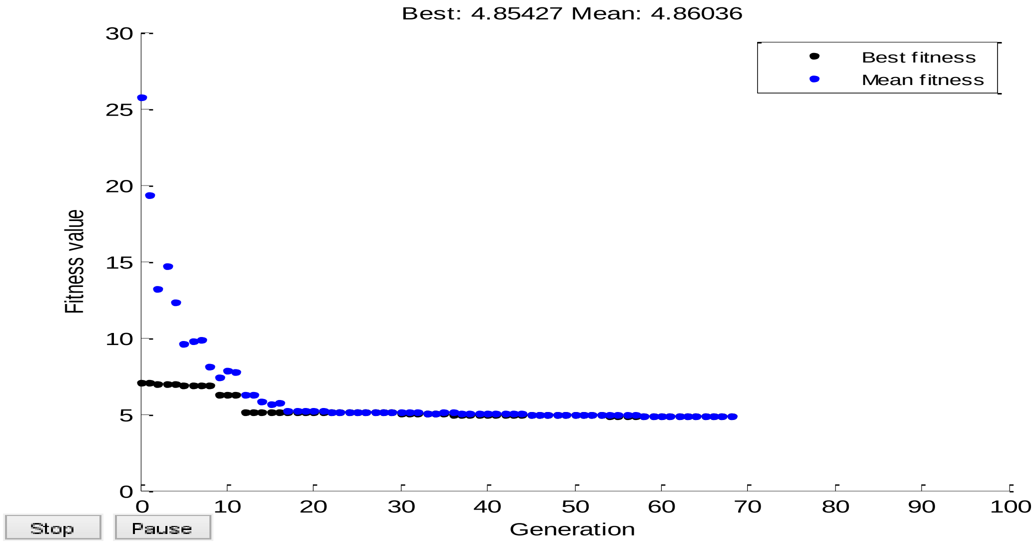

Fig.7:- Best cost value over generations

VII. RESULTS

The simulation results of the phase angles (after the outputs are changed by –30, 0, or +30%) and the outputs of lead-lag design are shown in Fig. 8 & 10. From these results, we can confirm that the proposed cost perform has better performance than the fitness perform.

When the outputs increase, the proposed lead-lag compensator suppresses power oscillations effectively. However, at the operating points where the outputs are decreased by more than 15%, the settling time of the proposed compensator is longer than that of the conventional compensator and compares the GA results with simulated annealing and f- mincon techniques.

TABLE 1:- GA Parameter Setting

	Ex. 1	Ex. 3
w_1	1/4	1/4
w_2	1/4	1/4
w_3	1/4	1/4
w_4	1/4	1/4
DT_p	0.1	0.6
MOS	0.03	0.03
MUS	0.02	0.02
ME_{ss}	0.01	0.01

TABLE 2:- Final Controller Parameters

	Ex. 1	Ex. 2
K	36.327893	6.789779
α	8.001244	57.193075
T_1	0.358476	0.447117
β	0.032749	0.000004
T_2	0.072637	0.415076
J	0.005429	0.031531

TABLE 3:- Actual Unit-Step Response

	Ex. 1	Ex. 3
T_P	0.008621	0.675675
OS	0.000000	0.028114
US	0.026773	0.039891
E_{SS}	0.015677	0.009998
J	0.005569	0.031531

VIII. CONCLUSION

A simple layout procedure of a lead-lag controller to satisfy or nearly meet the planning specification via genetic algorithmic program has been proffered in this research paper. A main aspect of our way is to incorporate the planning specifications directly into the cost perform or fitness performs in GA iterations. The proffered cost function is expressed in terms of peak time, percentage overshoot, settling time, rise time, and steady-state error of the unit step response. Computer simulation showed that the performances of our expected controllers are quite smart. It is interesting to investigate the work achievements of the proffered lead-lag compensators for time-delay systems or non-linear systems. This establishes interesting future research field.

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