International Workshop on Advanced Control
IWAC2014
November, 3rd-4th 2014, Guelma, Algeria.

Optimal Tuning of PID Parameters Using Genetic Algorithms

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Abstract **- This article aims to exploit the efficiency of optimization algorithms to regulate the parameters PID controller. We used genetic algorithms to minimize an error objective function between the frequency response function of a system controlled by a PID and the frequency response of a system with desired performances. The use of genetic algorithms helps for an optimal tuning of the parameters of the PID regulator employed with the presented systems.**

I. INTRODUCTION

Generally, the purpose of controlling systems is to keep it as close as possible to its optimum operating predefined specifications (imposed performances or conditions).

PID controllers meet more than 90% of industrial needs. They are widely used in industry due to its robustness and simplicity [1] [2] [3]. Unfortunately, despite the experience gained over the years, the chosen values for the parameters P, I and D are not always satisfactory, nor adapted to the process set [9].

Setting PID parameters has been a challenge for a long time for fine, economic, human cost adjustment and to get the best performance [4] [5]. A large amount of researches have addressed this problem and they proposed to determine the parameters of a PID controller [6] [7].

In this paper we propose to use genetic algorithms to determine the optimal PID controller parameters. Thus we minimize an error function between the open loop frequency response of a desired system and the controlled one.

The paper is organized as follows, n down into several parts: 2nd part we will explain the overall PID controller and 3rd party, we will generally defined as the genetic algorithms, and 4th party, exploiting the efficiency of the algorithms optimization in tuning PID controller parameters. By combining genetic algorithms with some conventional optimization methods, to the best results obtained for setting parameters of a PID controller

II. PID Controller

PID controller is a control unit that permits to regulate in closed loop a physical value of an industrial process.

The PID controller provide three main actions [9]. It provides a control signal u (t) taking into account the evolution of the output signal *y(t)* with respect to the nominal value *c(t)*. Eliminates static error due to the integral term. It predict the changes in the output of the system due to the derivative term. [8]

PID parallel:

$$\frac{U(s)}{E(s)} = K_R + \frac{Ki}{S} + K_d S \quad (1)$$

III GENETIC ALGORITHMS

Genetic algorithms are computer algorithms inspired by Darwin's theory [12]. They are optimization algorithms based on techniques derived from genetics and natural evolution, namely crossovers, mutations, selection… etc. [13].

Unlike operational research, genetic algorithms do not require special knowledge on how the considered problem should be solved. It is only necessary to evaluate the quality of the solution. In case of searching for the optimum of analytical functions, they do not use neither differentiability nor continuity.

The implementation of a genetic algorithm is simple, with a minimum specific programming problem. Indeed, the more the problem is complex, the more the genetic algorithm shows its superiority. [14]

A genetic algorithm searches the extreme of a function defined on a data space range. To use it, we must start, in the first step by encoding each point from the elements of the population in the search space. The mechanism of generating the initial population should be able to produce a homogeneous population of individuals that represent a basis for future generations.

An adaptive function is then defined, it returns a value called fitness, which represents an adaptation assessment of an individual.

In genetic algorithms a genetic operators should be also defined. They help diversify the population over generations and explore the search space.
The total number of generations is based on a stop criterion that depends on the problem in hand.

The algorithm of genetic algorithms is as follows: [16]

1. Produce an initial population of random individuals.
2. Iteratively perform the following sub-steps until satisfaction of the judgment criterion:
3. Assign a value to each individual in the population using the evaluation function.
4. Create a new population of chromosomes by applying genetic operators. These operations are applied to the selected chromosomes of the population with a probability based on their abilities:
(a) Reproduction: Reproduce an existing individual by copying the new population.
(b) Crossover: Create two new individuals from two existing individuals by genetic recombination of chromosomes by crossover operator.
(c) Mutation: create a new individual from an existing individual mutating.
5. The individual who represents the best fit of the objective function is considered as the best chromosome.

Each iteration is called a complete generation. A population is a group of candidate solutions in which the operations of reproduction, mutation and crossover is applied. Each generation is a new population.
According to the operating principle of genetic algorithms, one can identify the advantages of the conventional genetic algorithm optimization Methods [17]:

- The genetic algorithms use a coding parameters, not the parameters themselves.
- Genetic algorithms use a population evolution of solutions instead of a single solution (a larger search area limited by the size of the population).
- Genetic algorithms use probabilistic rules and non-deterministic transitions as tools to guide the exploration of the search space.
- Genetic algorithms use only the values of the function to be optimized, not its derivative or other auxiliary knowledge (they use global information from the entire space).

IV. Optimal Tuning Parameters of a PID Controller

In this section, we use optimization algorithms to minimize an error function that is defined in either frequency or time domain, between the desired system response and the real one, which will be controlled to check the specifications requirement.
The general scheme of the optimal tuning is showed in figure 01.

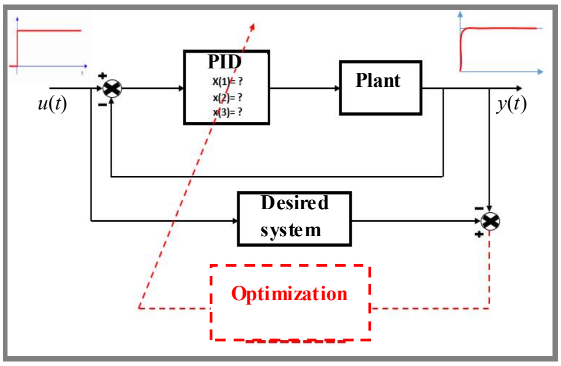

Fig. 1: Optimal tuning of a PID Controller.

The error function used in this paper represents the mean square error between the magnitude and the arguments of the desired system frequency response and the controlled plant one, over a range space of frequencies. We propose the simple form given by the following equation:

$$\min f = \sum_{w_{min}}^{w_{max}} (\|H_d(jw)\| - \|H_p(jw)\|)^2 + $$
$$+(arg(H_d(jw)) - arg(H_p(jw)))^2 \quad (2)$$

Where:
w_{max}, w_{min} are the frequencies range space limits.
H_d, H_p are the open loop frequency responses of the desired system and the controlled plant respectively.

V. Application and Simulation

In this part, we present two examples in which we propose a different desired system.

- Example 01:

In this example, the plant has the following transfer function:

$$H_p(s) = \frac{1}{s^2+10s+20} \quad \textbf{(3)}$$

We propose the desired system with the transfer function of the form given by:

$$H_d(p) = \frac{50p^2 + 400p + 350}{p^3 + 60p^2 + 400p + 350} \quad \textbf{(4)}$$

The proposed desired system meet the specifications requirement in time domain in term of settling time static error. Figure 2 shows the step response of the plant and the desired system.

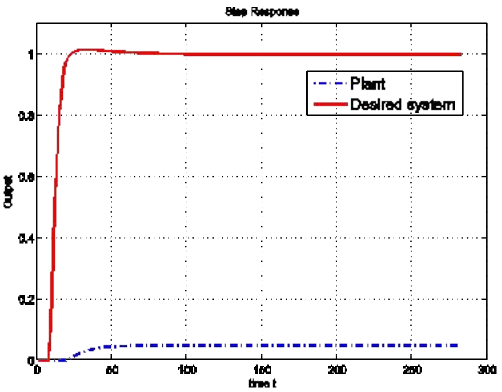

Fig. 2: Step response of the plant (uncontrolled system) and the desired one.

Figure 3 shows the frequency responses of the plant and the desired frequency response.

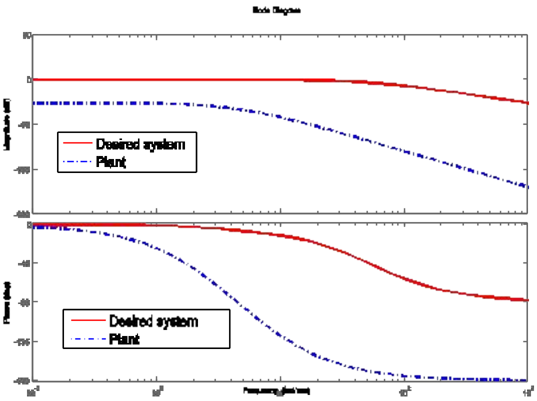

Fig. 3. The frequency responses of the plant and the desired frequency response.

From figure 2, we noticed that the plant has a very large static error and little slow response. The desired system has a very low static error and the settling time is a bit short.

The closed loop transfer function of the plant with the PID controller that is previously described, is given by:

$$w(p) = \frac{k_D.p^2+k_P.p+k_I}{p^3+(10+k_D)p^2+(20+k_P)p+k_I} \qquad (5)$$

With: $k_p = x(1), k_I = x(2), k_D = x(3)$

We can now use equation 2 as an objective function to be minimized using genetic algorithms.

The obtained results are as follows:

$$\begin{cases} k_p = x(1) = 398,296 \\ k_I = x(2) = 1165,484 \qquad minf = 0.0212 \cong 0 \\ k_D = x(3) = 49,898 \end{cases}$$

The controller transfer function is given by equation 6:

$$c(p) = 398,296 + \frac{1165,48\ 4}{p} + 49,898.p \qquad (6)$$

The step responses on the controlled and the desired systems as well as their bode diagrams, are shown in figures 4 and 5.

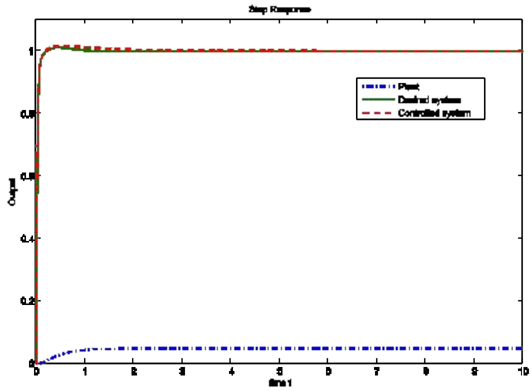

Fig. 4: Step responses of the plant, desired and controlled systems.

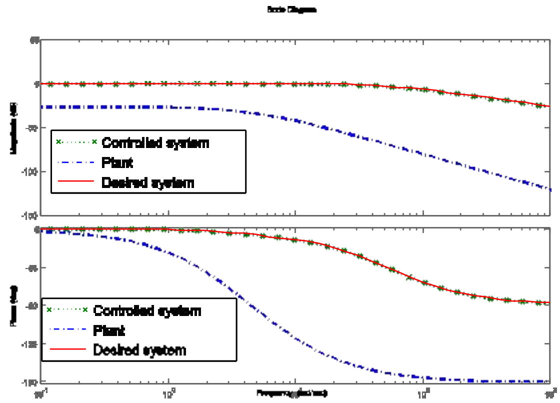

Fig. 5: Frequency responses of the plant, desired and controlled systems.

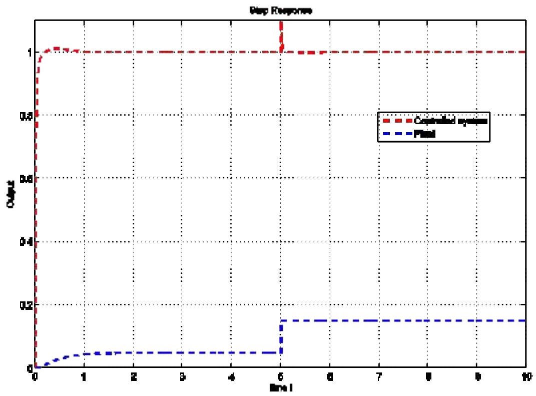
Fig. 6: disturbance rejection by the optimal PID Controller

VI. CONCLUSION

In this paper, we presented an optimal tuning method based on an evolutionary strategy. The genetic algorithm approach has shown a simple and easy use to implement the application, without requiring a detailed mathematical representation of the problem.

From the presented example, the comparison between the desired and closed loop controlled systems demonstrate that this approach is able to find optimal PID parameters

As a result, the presented method is flexible and applicable in a wide range of problems. The results show that the use of genetic algorithms can find the values of the PID parameters with a remarkable accuracy.

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