PID Controller Configuration and Tuning Based on Genetic Algorithms

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Abstract-- In this work, the power of the Genetic Algorithms (GA) in searching for an optimal solution (in a pre-determined hyper space) is used to design the suitable configuration and parameters of the Proportional-Integral-Derivative (PID) controller. In most industrial plants, the PID controllers are configured either in cascade, feedback or in feed forward topologies. Besides, for each of these configurations the tuning gains have to be fixed in order to meet the required specifications. Therefore, GA is utilized efficiently to select the proper PID configuration in the context of signal following approach as well as the best tuning gains for the selected configuration. The proposed design procedure is applied to linear and nonlinear plants. It reflects a tremendous design results that heavily relied on computer to get the required controller.

Key Words-- PID Controller, Genetic Algorithms, Signal Following Control.

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1. INTRODUCTION

In industry, the well-known PID controllers are widely used due to its simple in structure and parameters tuning. About 85 % of the industrial PID's are connected in cascade and its tuning procedure is well studied. However, other types (the feedback and feed forward) of PID configurations are also easy to implement digitally. On the other hand, tuning such different PID configurations is a cumbersome task especially if one can implement them all together. Therefore, evolutionary techniques, such as GA, are an intelligent approach to automate this design problem. Many researchers present their work on applying GAs to find optimum tuning PID gains. Indeed they are differ either in choosing their objective function [1][2], presenting unknowns (coding) [3], presenting design constraints [4], starting from Ziegler-Nichols tuning values then complete as fine tuning using Gas [5], or online GAs operation [6]. Work was published that concerning GAs tuning for different PID controller configurations [7]. Therefore, this work can be considered as an extension to that in [7] where the GAs is utilized efficiently to select the proper PID configuration as well as the best gains for this configuration in a so called signal following control.

2. THE DESIGN PROBLEM

The undertaken design control problem is to find the 'best' PID configuration in addition to find the optimal tuning gains that ensure certain objective function. The three configurations selected in this work are presented in Fig. (1),
Where:

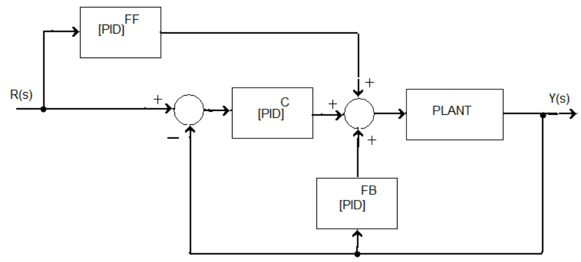

Fig. (1): The Three PID Configurations

$[PID]^{c}$ is a cascade configuration; $[PID]^{FB}$ is a feedback configuration, and $[PID]^{FF}$ is a feed forward configuration.
Each of these configurations is implemented as:

$$\frac{PID_{out}}{PID_{in}} = K_p + \frac{K_i}{s} + K_d s \qquad (1)$$

Therefore, analytic design procedure has to determine nine unknown tuning parameters (three for each configuration). Moreover, the designer has to choose the suitable configuration that meets the required specification and easy to implement depending on the plant conditions.

3. THE GENETIC ALGORITHM [8], [9]

The Genetic Algorithm (GA) is a direct random search technique, which can find the optimal solution in complex multi-dimensional search space. It is a model of natural evolution operators which manipulate individuals in a population over several generations to improve their fitness gradually. These individuals that, represent a candidate solution to the problem under consideration, often encoded as a bit string. Therefore, GA does not involve much experience about the optimal solution of the problem rather than deals with codes that represent the key parameters of the problem.

There are two basic issues in the GA; the first one is how to present the unknown parameters of the problem and this is called *coding*. Two common ways for coding are either real or binary coding. The GA requires a set of possible solutions called initial populations which are randomly produced. The second issue is how to qualify each individual (string) which is called the *fitness evaluation*.

4. THE COMPLETE GENETIC-BASED DESIGN PROCEDURE

The GA is a powerful tool to search in a predetermined hyperspace looking for the "best" solution that satisfies certain objectives with predetermined constraints. Design problem under consideration can be formulized in a manner solvable by GAs. The hyperspace is of a ten dimension as follows:

1- PID configuration code:

Different PID configurations are coded using nine bits as "1" is for non-zero value branch while "0" is for non existing branch. The nine bits configuration code is arranged as in Fig. (2).

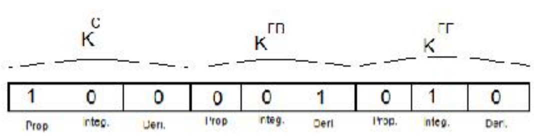

Fig. (2) GAs coding for PID configuration

The above code indicates that there are K_p^c, K_d^{FB} and K_i^{FF} as shown in the block diagram shown in Fig. (3).

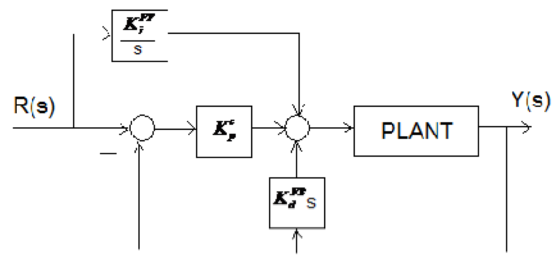

Fig. (3) The code interpretation of Fig. (2)

Of course some configurations are unrealizable such as [0 0 0 0 0 0] or having the first three bits to be zero as [0 0 0 # # # # # #] where "#" indicates either "1" or "0".

2- The gains of the existing branches

The gain of the branches that is coded by "1" is of the following unknowns:

K_p^c , K_i^c, and K_d^c are the unknown $[PID]^c$ parameters.

K_p^{FB}, K_i^{FB},and K_d^{FB} are the unknown $[PID]^{FB}$ parameters.

K_p^{FF}, K_i^{FF},and K_d^{FF} are the unknown $[PID]^{FF}$ parameters.

Hence each string will have 15 bits representation for each unknown gain (i.e. for K_p, K_i, and K_d). Therefore, the string length will be (9+15*9) bits as in Fig. (4).

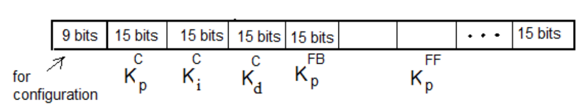

Fig. (4) The complete PID code

The objective function is suggested here to force the plant to follow the response of a predefined filter that reshapes the actual hard step input. Therefore, each GA solution (string s_i) has to minimize the following objective function [7]:

$$J(s_i) = \sum_{i=0}^{T_o} j_{s_i}(i) \cdots \cdots \cdots (2)$$

where,

$$j_{s_i}(t) = \begin{cases} -\left|e_{s_i}(t)\right| - \alpha(s_i) & if \left|e_{s_i}(t)\right| > \varepsilon \\ \varepsilon - \left|e_{s_i}(t)\right| - \alpha(s_i) & if \left|e_{s_i}(t)\right| \le \varepsilon \end{cases} \cdots\cdots (3)$$

$$\alpha(s_i) = \begin{cases} 0 & if\ s_i\ represents\ \ stable\ case \\ M & elsewhere \end{cases} \cdots (4)$$

T_0 is the number of the collected data sample, ε is the minimum accepted error (set to be 0.02), and $e_{s_i}(t)$ is the instantaneous error between the plant output and the model output for s_i string as:

$$e_{s_i}(t) = y_p(t) - y_m(t) \cdots \cdots \cdots (5)$$

In equation (5), $y_p(t)$ is the instantaneous plant output for s_i string parameters and $y_m(t)$ is the instantaneous model output. In equation (4) $\alpha(s_i)$ represents a penalty function for s_i string that gives an unstable solution (unwanted solution). In this work the unstable solution is that string which have fitness value more than M (M is set to be 10^6 indicating that instability occurrence).

5. ILLUSTRATIVE EXAMPLES

To illustrate the power of the proposed complete PID design procedure, similar examples that are taken in [7] are considered here;

(A) Example -1

Consider the following linear plant [10]:

$$G_{plant}(s) = \frac{0.05(1+s)}{(1+0.5s)(1+0.6s+0.1s^2)} \qquad (6)$$

It is required to reshape its step response so that the plant output will follow that signal given by the following filter:

$$G_{filter}(s) = \frac{1}{(1+0.5s)(1+0.3s)} \qquad (7)$$

Here it was found by trial and error that the best GA parameters are; Population size = 100, Cross over probability = 0.85 (single point), Mutation probability = 0.01, maximum number of generation is 1000, and the tournament selection method.

The first proposed genetic-based design procedure gives the following controller (minimum objective function = 29.782 according to Equation (2)):

$K_p^c = 10.2$, $K_i^c = 22.9$, and $K_d^c = 0.0$

$K_p^{FB} = 0.0$, $K_i^{FB} = 0.0$, and $K_d^{FB} = 7.05$

$K_p^{FF} = 0.0$, $K_i^{FF} = 0.0$, and $K_d^{FF} = 0.0$

The closed-loop block diagram for this case is shown in Fig. (5).

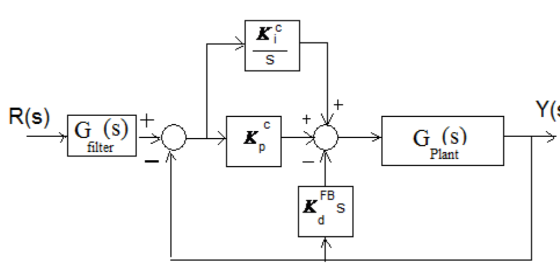

Fig. (5) The first proposed configuration for the plant of example-1

The system step response is illustrated in Fig. (6).

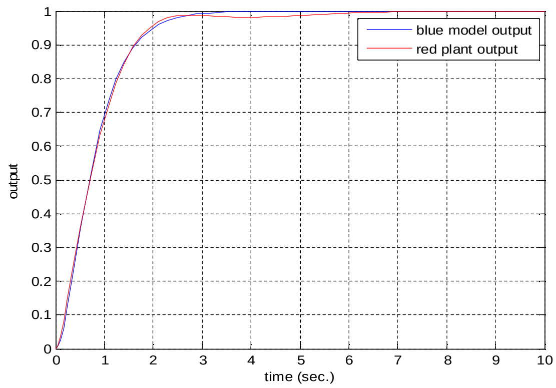

Fig. (6): The step response for the first proposed configuration of example-1

The proposed design procedure is also suggesting another configuration that gives a higher objective function (34.326) as shown in Fig. (7)

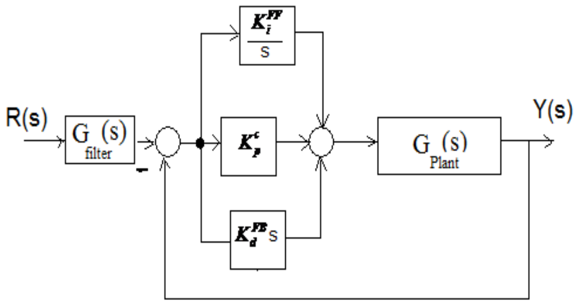

Fig. (7) The second proposed configuration for the plant of example-1

In this configuration, $K_p^c = 3.5, K_i^c = 21.9$, and $K_d^c = 1.1$.

The system step response is illustrated in Fig. (8)

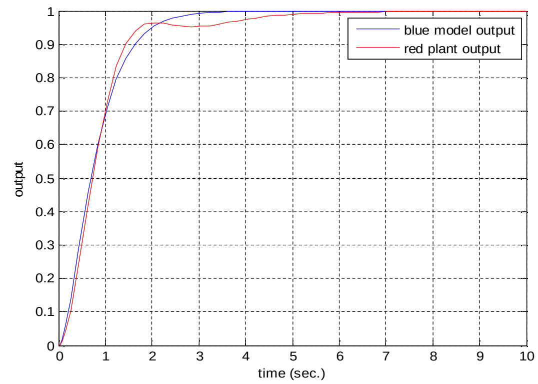

Fig. (8): The step response for the second proposed configuration of example-1

(B) Example -2

In this example a non-linear system will be considered. The water level control is shown in Fig. (9) [11]:

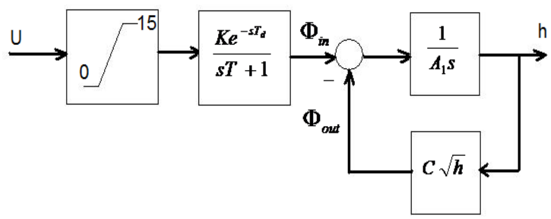

Fig. (9) The water level control problem [11]

The system transfer function is as follows

$$\varphi_{in}(s) = \frac{Ke^{-sT_d}}{sT+1}U(s), \qquad \varphi_{out}(s) = C\sqrt{h(s)},$$

then

$$h(s) = \frac{1}{A_1(s)}(\varphi_{in}(s) - \varphi_{out}(s)) \qquad (8)$$

Where U(s) is the control pump voltage , h(s) the water level in meters, T_d is the system time delay (0.65 sec.) , T is the system time constant (0.5 sec.) , $K = 10^{-4} m^3 / V.\sec.$,and

$$C = A_1 \sqrt{\frac{2A_2^2}{A_1^2 - A_2^2} g} \qquad (9)$$

In equation (9) $A_1 = 6\times10^{-3} m^2$, $A_2 = 3\times10^{-4} m^2$, and g is the gravity. It is required to have a step response that is acceptably close to that of a 1_{st} order system given by

$$G_{filter}(s) = \frac{1}{s+1} \qquad (10)$$

Here the GA parameters are; Population size = 150, Cross over probability = 0.8(double points), and the mutation probability = 0.02 .The other parameters including the objective function are similar to those used in example-1.

The first proposed genetic-based design procedure gives the following controller configuration (minimum objective function = 21.094 according to Equation (2)):

$K_p^c = 40$, $K_i^c = 4.8$, and $K_d^c = 0.0$

$K_p^{FB} = 0.0$, $K_i^{FB} = 0.0$, and $K_d^{FB} = 0.0$

$K_p^{FF} = 0.0$, $K_i^{FF} = 0.0$, and $K_d^{FF} = 28.7$

The closed-loop block diagram for this case is shown on Fig. (10)

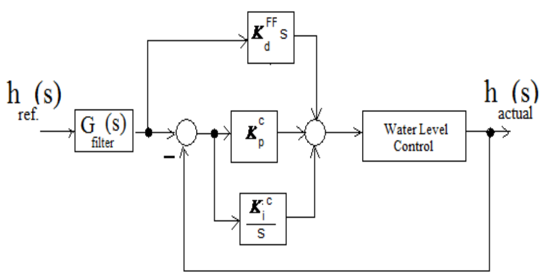

Fig. (10): The first proposed configuration for the plant of example-2

The system step response is illustrated in Fig. (11)

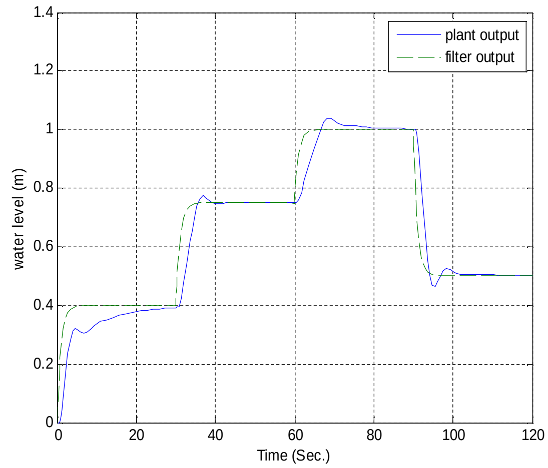

Fig. (11): The response for the first proposed configuration of example-2

However, the proposed design procedure can also present another topology that gives higher objective function (27.898) as shown in Fig. (12).

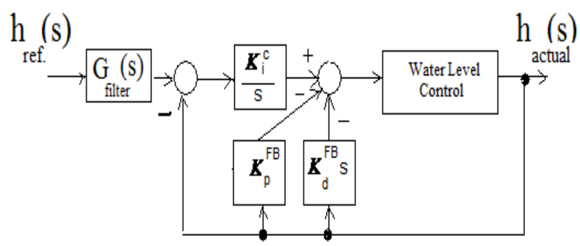

Fig. (12): The second proposed configuration for the plant of example-2

In this configuration, K_p^{FB} = 29.9, K_i^c = 9.1, and

K_d^{FB} = -12.06.

The system step response is illustrated in Fig. (13)

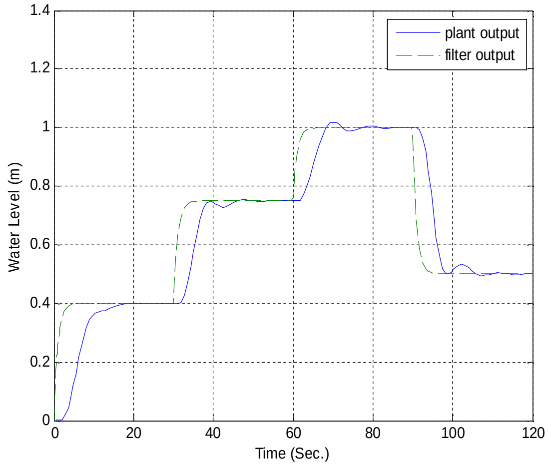

Fig. (13): The response for the second proposed configuration of example-2

6. CONCLUSIONS

The inclusion of selecting the PID configuration process as an additional task to the already exist GAs task of finding the optimal tuning gains is discussed in this work. It is found that the capability of the GAs can be extended more to fully exploit it in the context of completely solve the design of PID controllers. Hence, the designer can then decide which configuration will choose that satisfies the requirements and the one that easily implemented according to the plant conditions, hardware availability, and easy accessibility. The proposed design procedure is illustrated in two examples (linear and nonlinear plants).For each case, the best two PID configurations are presented together with their optimal tuning gains. These configurations are chosen as the best ones that satisfy faithfully following the predefined command input reshape filter signal.

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