A comparative study of PID-PSO and Fuzzy-PID controller design for Time Delay System

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Abstract— **This paper present comparative between classical and advanced control technique with classical PID controller, Fuzzy controller, Fuzzy-PID controller, PID-PSO controller applied to control on real system (Experiment setup of a flow control). In order to ensure all performances required by several complex industrial process. Detailed descriptions of the process with different mathematical models (with time delay) are exposed. The principal of different technique has been described before simulation section. Finally several simulations have proved the efficiency of the PID-PSO control in term of stability, robustness and precision**

Keywords- Modeling; conventional PID, Fuzzy; Fuzzy-PID, PID-PSO, experimental.

I. INTRODUCTION

In the face of rapid technological development and increasing need for precision and robustness, automated systems have constantly evolved, leading inevitably to increasingly complex control structures. Automatic is the discipline which generally deals with the system control, therefore it has a very important character in the industrial plant, which brings solutions, study methods and systematic analysis approaches. To be competitive, an industrial process must be well controlled. Indeed, competitiveness requires keeping process values as close as possible to its required optimum performance and process conditions: such as the products quality, production flexibility, energy saving and safety of personnel, facilities and the environment. The objective of automatic regulation or servo-control of a process is to keep the process values as close as possible to its optimum of operating points, predefined by the process specification (imposed conditions or performance). Before going design the controller architecture and structure and in case of unknown process parameters, an identification phase is mandatory. Different identification methods are existed in the literature [1-2-3].

In our study we are interested in the analogue flow control system [4] by computing its mathematical model via applying different identification methods (Broïda, Strejc.) and synthesis of its control laws using several types: parallel PID, Fuzzy, Fuzzy pre-compensated and Fuzzy PID controllers and then at the end we checked the simulation results with the process experiments.

II. SYSTEM DESCRIPTION

Our process is the closed loop flow control, which is represented by P&ID diagram with the follows figure [5].

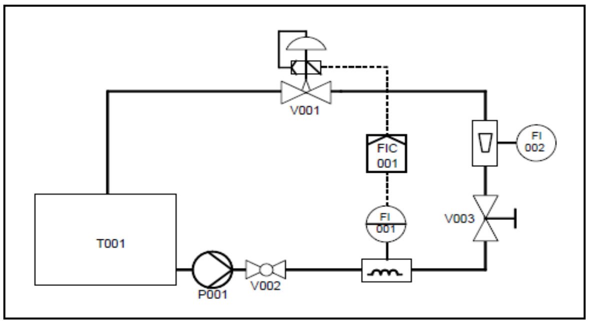

Fig. 1. Flow control diagram [4].

With : FIC :Flow Indicator and Controller; P001 : Centrifugal pump; V002 : Ball Valve; FI : Flow Indicator; V001: Control alve; T001: Tank;V003: Screwdown valve

The control of flow mesured with flow Rate Sensor is assured with closed and open of electro-pneumatic valve (v001). Then the model (open valve/ flow) is illustrated in the following formula [5]:

$$G(s) = \frac{0.89686}{20.539 \cdot s + 1} \cdot e^{-0.5 \cdot s} \quad (1)$$

The G(s) is the model that represents better the real system. To assure the performances (stability, presicion and robustenss) of system with time delay model , we have opted to used different controller PID, fuzzy controller,PID-PSO, fuzzy-PID

III. FUZZY CONTROLLER

The kind of a structure a fuzzy controller will have will primarily depend on the controlled process and the demanded quality of control. Since the application area for fuzzy control is really wide, there are many possible controller structures, some differing significantly from each other by the number of inputs and outputs, or less significantly by the number of input and output fuzzy sets and their membership functions forms, or by the form of control rules, the type of inference engine, and the method of defuzzification. All that variety is at the designer's disposal, and it is up to the designer to decide which controller structure would be optimal for a particular control problem [5]. Despite the variety of possible fuzzy controller structures, the basic form of all common types of controllers consists of[6-9]:

- Input fuzzification (binary-to-fuzzy [B/F] conversion); Fuzzy rule base; Inference engine.
- Output defuzzification (fuzzy-to-binary [F/B] conversion).

The basic structure of a fuzzy controller is shown in the following figure.

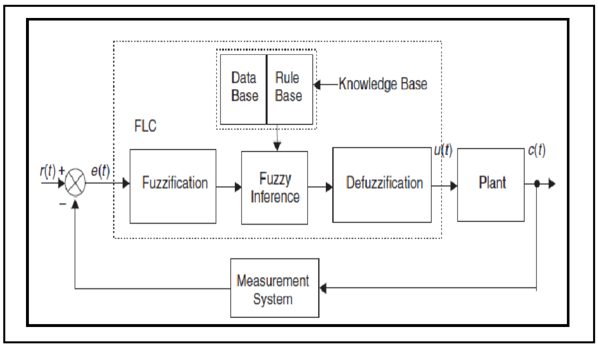

Fig. 2. Fuzzy logic control structure

A brief explanation of these four elements is given below:

- **Fuzzification:** Here, the crisp signal e(t) is converted into suitable linguistic fuzzy set.
- **Rule Base:** The rule base is the heart of a fuzzy controller, since the control strategy used to control the closed-loop system is stored as a collection of control rules.
- **Inference Engine:** The basic operation of the interference engine is that it "infers," ie., it deduces (from evidence or data) a logical conclusion. The inference engine is a program that uses the rule base and the input data of the controller to draw the conclusion. The conclusion of the inference engine is the fuzzy output of the controller, which subsequently becomes the input to the defuzzification interface.
- **Defazzification interface:** In this last operation, the fuzzy conclusion of the inference engine is defuzzified, i.e., it is converted into a crisp control signal. This last signal is the final product of the fuzzy logic controller, which is, of course, the crisp control signal to the process [8].

IV. PARTICLE SWARM OPTIMIZATION WITH PID

The Particle Swarm Optimization (PSO) is evolutionary computational technique based on the movement and intelligence of swarms looking for the most fertile feeding location; it was developed in 1995 by James Kennedy and Russell Eberhart. This algorithm is simple, easy to implement and few parameters to adjust mainly the velocity. It's inspired by social behavior of birds and fishes and it's combines self-experience with social experience and applies to concept of social interaction to problem solving. The goal of Optimization is to find values of the variables that minimize or maximize the objective function while satisfying the constraints. The optimization needs the good mathematical model of the optimization problem and an algorithm that should have robustness (good performance for a wide class of problems), efficiency (not too much computer time) and accuracy (can identify the error). The optimization is based in population; it has been applied successfully to a wide variety of search and optimization problems. In this technique, a swarm of n individuals communicate either directly or indirectly with one another search directions (gradients). PSO technique is not only a tool for optimization, but also a tool for representing sociocognition of human and artificial agents, based on principles of social psychology. A PSO system combines local search methods with global search methods, attempting to balance exploration and exploitation. The Population-based search procedure in which individuals called particles change their position (state) with time. The Particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience, and according to the experience of a neighboring particle, making use of the best position encountered by itself and its neighbor. Suppose that the search space is D-dimensional, then the ith particle of the swarm can be represented by a D-dimensional vector $X_i = [x_{i1} x_{i2} \dots x_{iD}]^T$. The velocity of the particle can be represented by another D-dimensional vector $V_i = [Vi(1)Vi(2) \dots Vi(D)]^T$. The best previously visited position of the ith particle is denoted as $P_i = [p_{i1} p_{i2} \dots p_{iD}]^T$. Defining ''g'' as the index of the best particle in the swarm, where the gth particle is the best, and let the superscripts denote the iteration number, then the swarm is manipulated according to the following two equations.

$$V\,i\,(t+1) = w\,.V\,i(t) + c1.r1\,.\big(pbesti\,(t) - xi(t)\big) + c2.r2\,\big(gbesti\,(t) - xi\,(t)\big) \quad (18)$$

$$xi(\,t+1) = Vi\,(t+1) + xi\,(t) \quad (2)$$

where t = 1, 2, . . . , D; i= 1, 2, . . . , M, and M is the size of the swarm (i.e. number of particles in the swarm); $c1$, $c2$ are the positive values, called acceleration constants; $r1, r2$ are the random numbers uniformly distributed in [0, 1]. Typically $w(t)$ is reduced linearly, from w_{start} to w_{end}, each iteration, a good starting point is to set $w_{start}\ to$ 0.9 and $w_{end}\ to$ 0.4 [10-15].

$$w(t) = \frac{(T_{max}-t)\times(w_{start}-w_{end})}{T_{max}} + w_{end} \quad (3)$$

Thought V_{max} has been found not to be necessary in the PSO with inertia version, however it can be useful and is suggested that a $V_{max} = X_{max}$ be used [14]. The original procedure for implementing PSO is as follows:

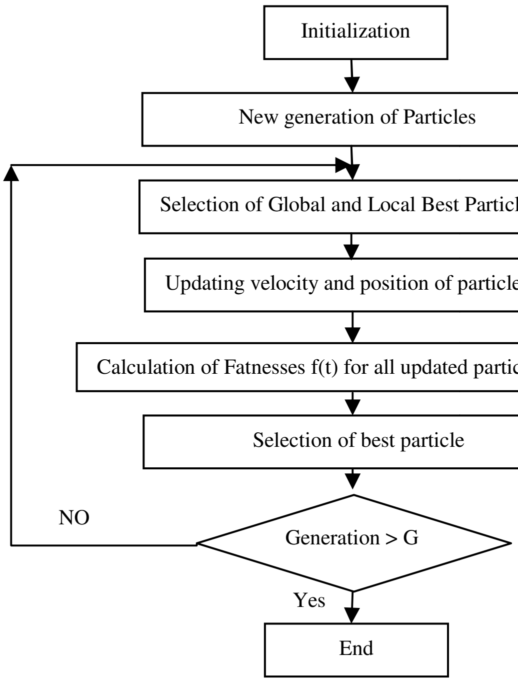

Fig. 3. Flow chart of PSO algorithm

In PID controller design methods, the most common performance criteria are integrated absolute error (IAE), the integrated of time weight square error (ITSE), integrated of squared error (ISE) and Mean Square Error (MSE) [14-15]. These four integral performance criteria have their own advantages and disadvantages. For example, disadvantage of the IAE and ISE criteria is that its minimization can result in a response with relatively small overshoot but a long settling time because the ISE performance criterion weights all errors equally independent of time. Although the ITSE performance criterion can overcome the disadvantage of the ISE criterion, the derivation processes of the analytical formula are complex and time-consuming [15]. The essential function of a feedback control system is to reduce the error, e(t), between any variable and its demanded value to zero as quickly as possible. Therefore, any criterion used to measure the quality of system response must take into account the variation of e over the whole range of time. Four basic criteria are in common use:

$$Integral\ squared\ erroe\ (ISE) = \int_0^\infty e^2 dt \tag{4}$$

$$(ITSE) = \int_0^\infty t.e^2(t)dt \tag{5}$$

$$(IAE) = \int_0^\infty |e(t)|\, dt \tag{6}$$

$$(ITAE) = \int_0^\infty t.e(t)dt \tag{7}$$

In this work we use parallel PID, and the coefficients Kp, Ki, Kd are determined by the PSO algorithm using ITSE performance criteria (figure 4).

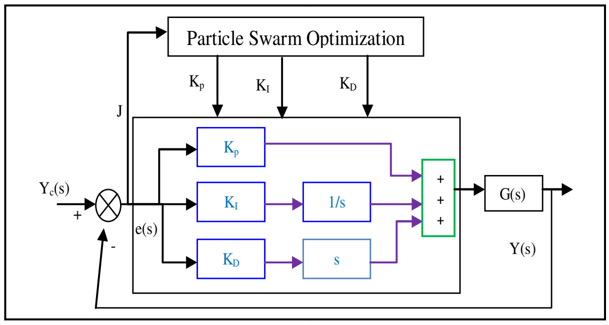

Fig. 4. PID parametrs based on PSO

With : J: ITSE performance criteria (fitness function); H(s) : transfer function of process (linear model); Yc: consigne; Y: output system; e: error;

A set of good control parameters K_P, K_I and K_D can yield a good step response that will result in performance criteria minimization in time domain.

V. SIMULATION

The simulation was done with closed loop and step signal as input. Different diagram blocks have been used with different controllers types.

A) *Conventional PID controller*

The PID controller parameters are extracted using the pidtool command. The following figure shows that our system is regulated by a parallel PID controller. We use the following transfer function of conventional PID controller is:

$$G_{PID}(s) = Kp + Ki \times \frac{1}{s} + Kd \times s \tag{8}$$

$$with\ Kp = 10.5, Ki = 0.808, Kd = 1.87$$

The following figure shows the step response of our system using the conventional parallel PID and PID-PSO, we note the following results: $Setting\ time\ = 19.4\ sec,$

$$Rise\ time\ = 3.54\ sec, Overshoot\ = 3.54\%$$

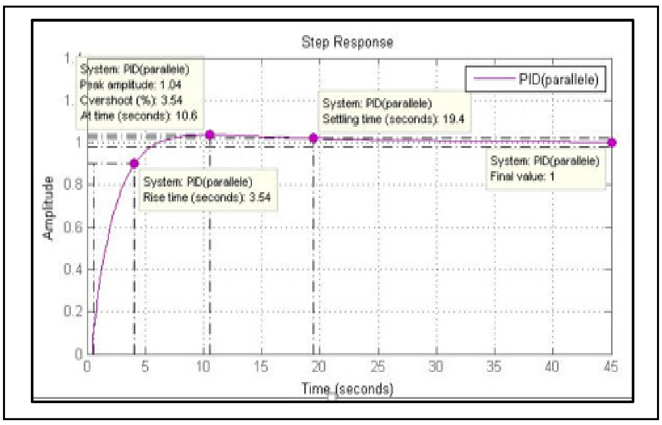

Fig. 5. step response with Parallel PID

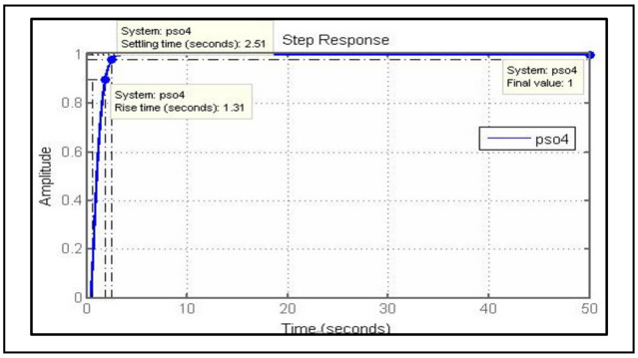

Fig. 6. Step response in closed loop with PID-PSO controller

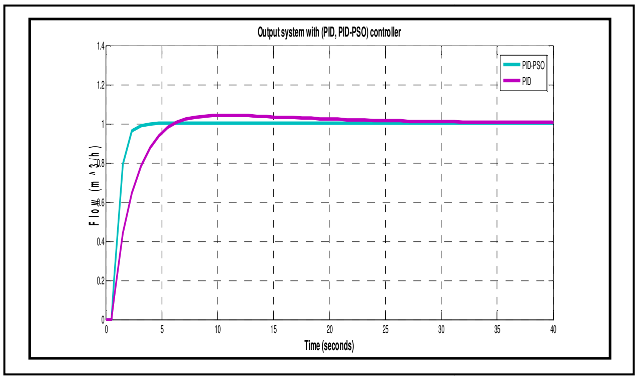

Fig. 7. The step responses of the different correctors (pid and pid-pso controller).

B) *Fuzzy logic controller(FLC)*

We use fuzzy logic to control our system. The following figure shows the block diagram of the system controlled by fuzzy logic controller.

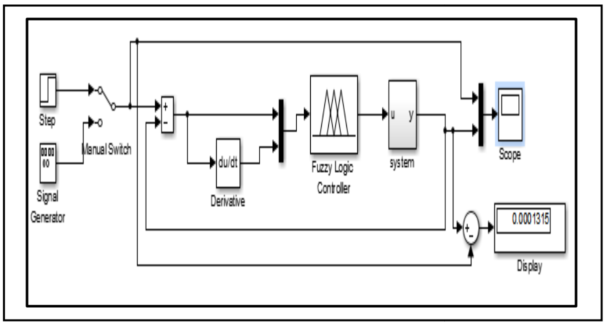

Fig. 8. Block diagram with fuzzy logic controller

This membership function is equivalent to the characteristic function of a classical set [7]. In our example, we will have to define membership functions for each fuzzy subset of each of our five variables:

- Input 1: Error. Subgroups: large negative GN, negative N, zero Z. Positive P, Large positive GP.
- Input 2: Derived from error. Subgroups: large negative GN, negative N, zero Z. Positive P, Large positive P.
- Output: Control of the flow of the valve. Subgroups: large negative GN, negative N, zero Z. Positive P, Large positive P.

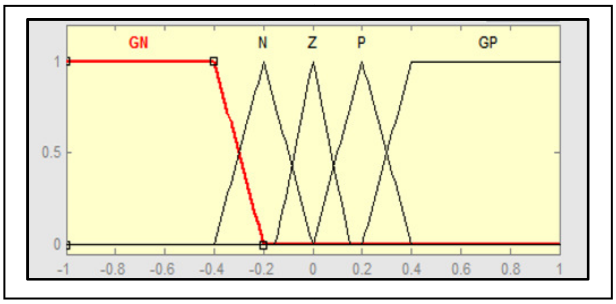

Fig. 9. The error membership function for G(s).

- The fuzzy rules

The fuzzy rules that make it possible to achieve the command according to the error values and its variation are in the following table: Each rule is composed of premises linked by the AND, OR operators and gives rise to an implication by the operator THEN.

TABLE I. FUZZY RULES .

Δe	GN	N	Z	P	GP
GN	GN	GN	N	N	Z
N	GN	N	N	Z	P
Z	GN	N	Z	P	GP
P	N	Z	P	P	GP
GP	Z	P	P	GP	GP

After applied this rules we found the following result:

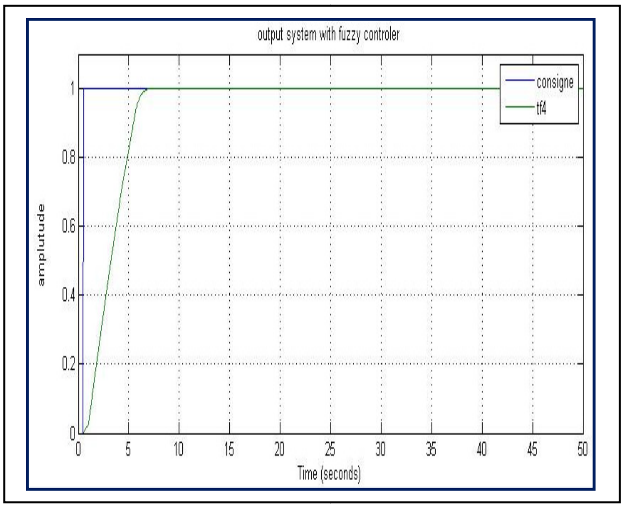

Fig. 10. Step response in closed loop with fuzzy logic controller.

C) *Pre-compensated fuzzy controller*

The figure shows the basic control structure. The system consists of a fuzzy pre-compensator.

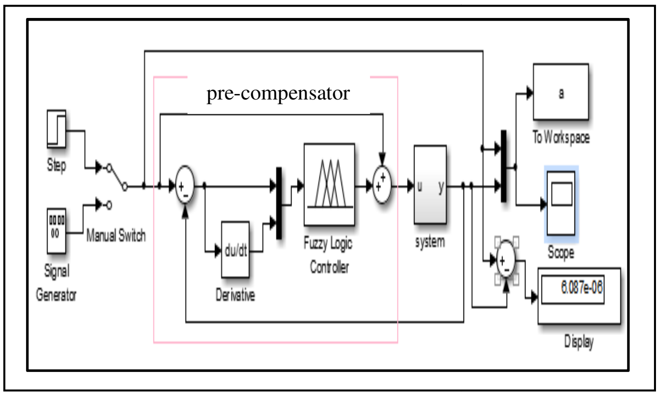

Fig. 11. Block diagram with pre-compensator fuzzy logic controller

The designed rules are presented in the table (III). To explain how these rules were obtained, consider, for example: Suppose that the control signal is a constant E (s), the error e (s) is zero, and the error variation Δe (s) is a negative number. This means that the output S (s) = E (s) -e (s) increases, that is the direction of overshoot. To compensate it, we reduce the control signal. This corresponds to the application of a correction term μ (s) which is negative. Therefore, we get the rule "if the error is zero and the variation error is negative, and then issues a negative correction term".

TABLE II. FUZZY RULES (PRE-COMPENSATED).

Δe / e	GN	N	Z	P	GP
GN	GN	GN	N	N	Z
N	GN	N	N	Z	P
Z	GN	N	Z	P	GP
P	N	Z	P	P	GP
GP	Z	P	P	GP	GP

With the same area, we find the following result.

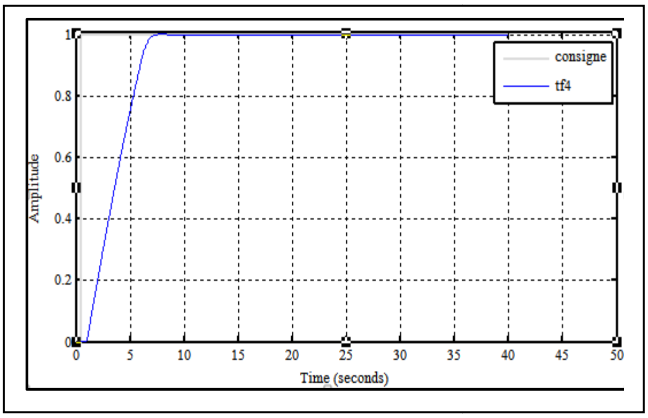

Fig. 12. Step response in closed loop with fuzzy pre-composator.

D) *Fuzzy Controller Hybrid and PID*

The system consists of a Hybrid Fuzzy Controller and PID, a hybrid system as shown in figure (13), was developed to use the advantages of PID and fuzzy controllers.

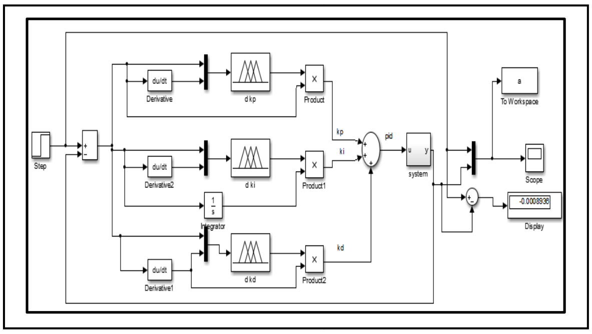

Fig. 13. Block diagram with fuzzy-PID controller.

We need to redefine a membership functions for each fuzzy subset of each our five variables:

- Input 1: Error. Sub-sets: high negative GN, negative N, zero Z. Positive P, high positive GP.
- Input 2: Error derived. Subgroups: high negative GN, negative N, zero Z. Positive P, high positive GP.
- Output : dkp Subsets: small pt, high G.

We follow the same method for the other PID parameters (Ki and Kd), then we obtain the following result:

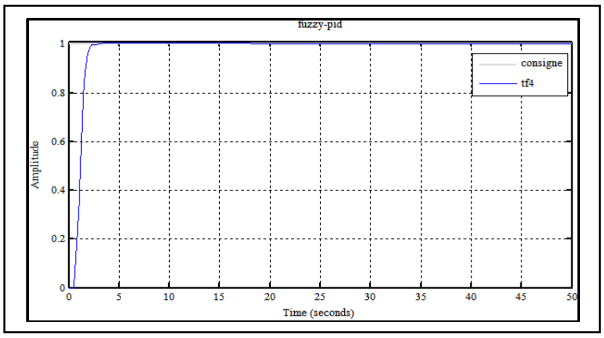

Fig. 14. Step response in closed loop with fuzzy-pid controller.

The figure below shows all the step responses of various correctors used to improve the performance of our system (for G(s)).

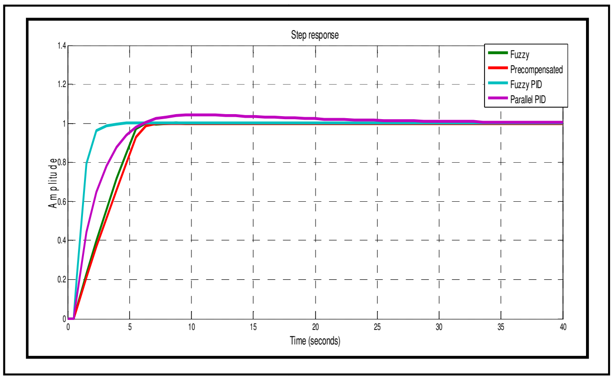

Fig. 15. The step responses of the various correctors (G(s)).

In the following table, the correctors will be classified in ascending order according to the characteristics obtained from their step responses.

TABLE III. SUMMARY OF THE RESULTS OBTAINED FOR G(S) (CLASSIFICATION BY CHARACTERISTICS

controller	Setting time (sec)	Overshoot	error	Final value
PID-PSO	**2.51**	**pas**	**-0.0007524**	**1**
Fuzzy	5.625	pas	0.0001315	1
fuzzy PID	6.4	pas	-0.0001597	1
Fuzzy Pre-compensator	6.5625	pas	0.000006087	1
PID	19.4	1.04	0.0008018	1

According to the classification of the results obtained, it is observed that the Fuzzy PID corrector is the most suitable for improving the performance of G(s) system according to the specifications.

E) *Implementation on the real system*

we have used the parameters of pid-pso (Kp = 10.42, Ki = 0.202456, Kd = 0.00321236) in real system with different inputs: (0-50), (0-100) and the obtained results are illustrated in the following curves:

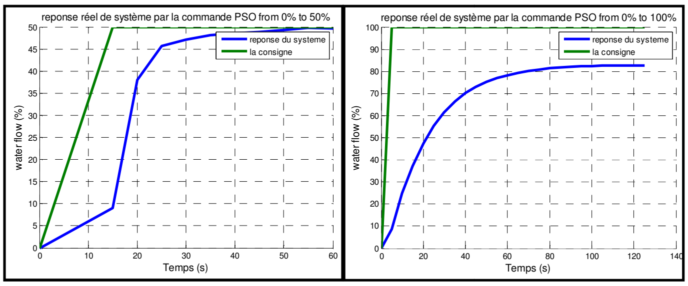

Fig. 16. The real response to the equilibrium points (optimized PID)

The following curve shows the system responses of the two PID-PSO and parallel PID with input (0-50).

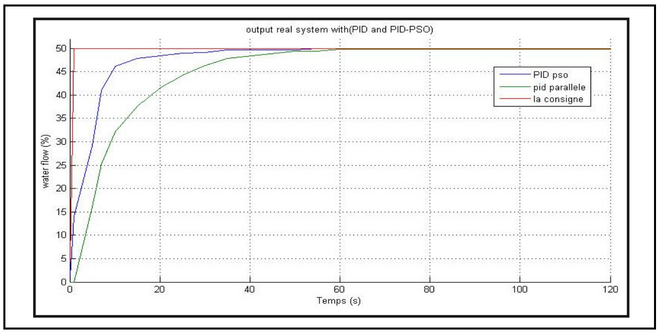

Fig. 17. The real responses with paralelle PID and PID based on PSO controllers.

From FIG. 17, we have constated that the pid controller optimized by PSO algorithm make the system response faster and the precision is best.

VI. CONCLUSION

In this work, we presented a comparative study of different conventional and advanced control techniques applied on a real system (RT 450 flow control installation process). The classic control techniques based on a PID controller and advanced techniques based on controllers like PID Fuzzy, Fuzzy and Fuzzy pre-compensated, PID-PSO. The actual system is modeled by a linear model with delay. The results obtained show that the advanced control technique based on PID-PSO offers better performance compared to other techniques (PID, fuzzy-PID, Fuzzy or Fuzzy pre-compensated controllers). The results obtained are really satisfactory, which allowed us to try them on the system which affirmed the results of simulation.

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