IDENTIFICATION AND IMPLEMENTATION OF A FUZZY CONTROLLER IN A HYDRAULIC SYSTEM

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Abstract. *Although PID control is the most used in the industry today, it can be unsatisfactory in non-linear processes, with transport delays or time-varying parameters. This limitation can be overcome by using intelligent controllers, such as Fuzzy. It provides answers appropriately to specific situations of the problem, making the control adapt to new situations. This work presents the comparative study between PI and Fuzzy controllers applied in a hydraulic plant. The plant was identified using the First Order Transfer Function Model and modeled in Matlab. The data were acquired by measuring the flow rate for different pump inputs. The controller models for identified plant were tested in simulink. The Fuzzy controller anticipated corrective actions when analyzing the trend of the values of the variable by the variation of the error value. The PI controller was submitted to the same inputs, but obtained better performance in the delay, rise, accommodation and peak times, despite having a slower transient response than the Fuzzy controller. Despite delayed responses, the Fuzzy controller is more suitable than the PI controller when applied to the hydraulic plant. Delays become negligible if considered the benefits produced by the low-overhead.*

Keywords: *Control Flow, Fuzzy, PI, Matlab*

1 INTRODUCTION

The disciplines related to control systems in the undergraduate courses in the area of technology and engineering present a series of theoretical concepts and are supported by computational simulations. According to GAMBOA (2003), experimental practice is the sole criterion of scientific veracity and theory is formed based on the effective repercussion of human action. Considering this aspect, and that in the control subjects we have many variables to be considered, the work with didactic plants provides an efficient form of theoretical validation, thus consolidating the study presented in the classroom.

Man's desire to develop techniques and equipment that would replace his work in order to increase the safety of his professional environment, obtain greater quality and speed in production has been a determining factor for technological progress throughout history. In industry, the need to control systems and processes has proved to be of fundamental importance in the vast expansion of the supply of available goods. Manual control, the first form of control used by man, and still present in many processes, presents the need for a human operator who must know the system and have reasonable experience and ability (SOUZA, 2012).

Aiming for greater productive efficiency in industries, engineering and technology professionals have sought inspiration in the workings of the human mind to solve complex problems, (LUNA FILHO *et al*, 2002). The techniques of Fuzzy Set Theory together with Fuzzy Logic have reached the most diverse application areas, solving several processes of industrial imprecision. One of the most in-depth techniques is Fuzzy Control, which has enabled the automation of several processes, ranging from domestic tasks to the control of industrial processes (AMENDOLA et al, 2004).

The Fuzzy controller relates the inputs and outputs of the system by adding linguistic values to them, which allows the system to provide satisfactory performance to the system, providing a control that does not require calculations or equations (VALE, 2007).

As in the study of control systems we have many variables to consider, working with a Professional Didactic Plant facilitates the implementation of such systems. Therefore, the present work presents the simulation and implementation of a Fuzzy controller in a real Hydraulic Plant for flow control using Matlab software (MATHWORKS, 2017).

2 MATERIALS AND METHODS

The Hydraulic Plant shown in Fig. 1 is composed of a stainless steel structure where the equipment is fixed. The plant has two centrifugal motors, however, in this work only one was used. The plant also has four pressure sensors and two flow sensors, however, only one flow sensor was used in this work.

Figure 1. ElettronicaVeneta Model SPCP / EV Hydraulic Plant

To implement the control we followed the following steps: Data Acquisition, System Identification and Fuzzy Controller.

2.1 Data Acquisition

To acquire plant data a unit step was introduced in the WEG CFW11 frequency inverter which later controls the hydraulic pump installed in the plant, as can be seen in the diagram of Fig. 2.

Figure 2. Steps for activating the hydraulic pump

From this step was acquired the values of the flow sensor, a device that transforms a fluid's flow into electrical voltage, through a National Instruments Acquisition Data Acquisition (NQ-6009) Data Acquisition Device, which acts as the interface Between a computer and electrical sensor signals. Its operation is basically as a device that scans analog input signals, electrical voltage, so that a computer can interpret them (NATIONAL INSTRUMENTS, 2017). According to the diagram in Fig. 3.

Figure 3. Steps for computer data acquisition.

These values acquired by the sensor are proportional to the voltage value of the DAQ, that is, the values that have a scale ranging from the minimum of 0 to the maximum equal to 5 Volts, are then compared with the values of a flowmeter and thus, calibrated so that the voltage acquired is converted into a flow rate in liters per minute.Tests were performed with different input steps for better data analysis and more accurate gauging.

2.2 Identification and System Validation

From ancient times man has sought to create methods that mathematically describe real systems to help him understand and control them (AGUIRRE, 2007). With the increasing computational development several models of identification were created so that the professional in engineering and technology does not need to have previous knowledge of the system, being in charge of the software all the mathematical tooling.

To identify the hydraulic plant we use the First Order Transfer Function Model. The transfer function for a system can be defined as the relation between the input and the output of the system in the Laplace transform domain. Therefore, for a first-order transfer function, we have:

$$G(s) = \frac{y(s)}{u(s)} = \frac{K}{\tau s + 1} \tag{1}$$

K is the gain, and τ is the time constant that characterizes the speed with which the system responds to the determined input. The longer the time constant, the slower the dynamic response to an input disturbance (AGUIRRE, 2007).

Applying the unit step response in Eq. (1) and obtaining the inverse Laplace transform, we have the following equation:

$$y(t) = K(1 - e^{-t/\tau}) \qquad (2)$$

In order to identify the plant by the Transfer Function Model, the Matlab Systems Identification Toolbox was used, since it allows the creation and use of models of dynamic systems that are not modeled. For such an application only measured input and output data are needed. These data were obtained in the Acquisition stage, where the input is represented by the voltage value of the DAQ and the output is the flow. The model found was:

$$G(s) = \frac{15.14}{7.924s + 1} \qquad (3)$$

In Figure 4, we can see that the model presented in Equation 3 presents a compatibility of 79.19% for data validation.

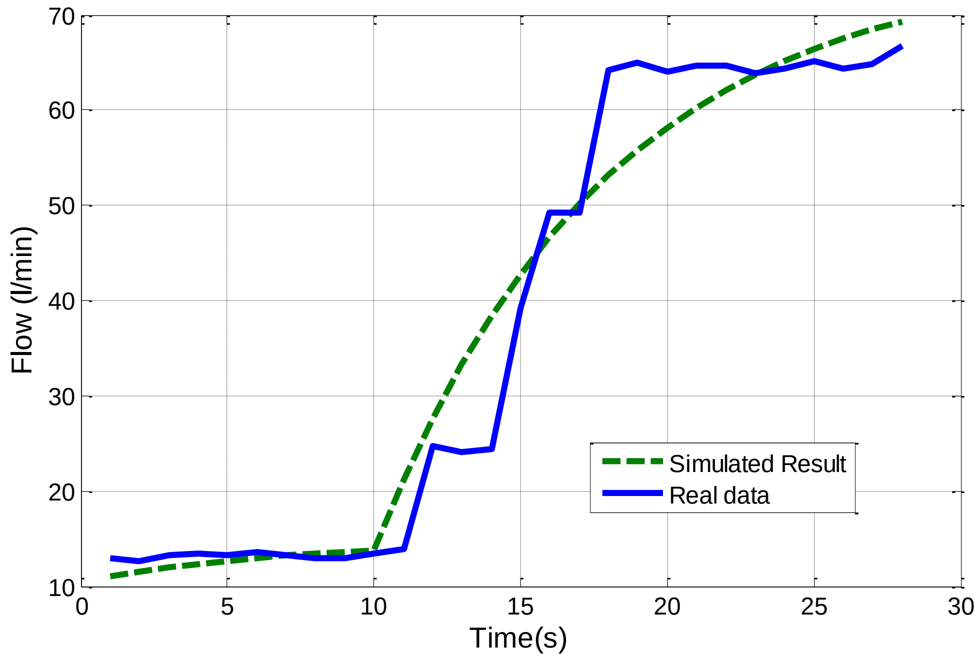

Figure 4. Identification and Validation of the Hidraulic System.

However, it can be observed that there is an error present in the graph of Figure 4, since, while the flow reaches its maximum value at 65 l / min, the Estimated Function for the model continues to grow until it stabilizes at 72.3 l / min . To correct this error a new simulation was performed to identify the plant by the Second Order Transfer Function Model using the Matlab Systems Identification Toolbox. The model found was:

$$G(s) = \frac{1.071}{s^2 + 0.3349s + 0.0878} \qquad (4)$$

In Figure 5, we can see that the model presented in Equation 4 shows a compatibility of 88.45% for data validation and that the error shown in Figure 4 no longer exists.

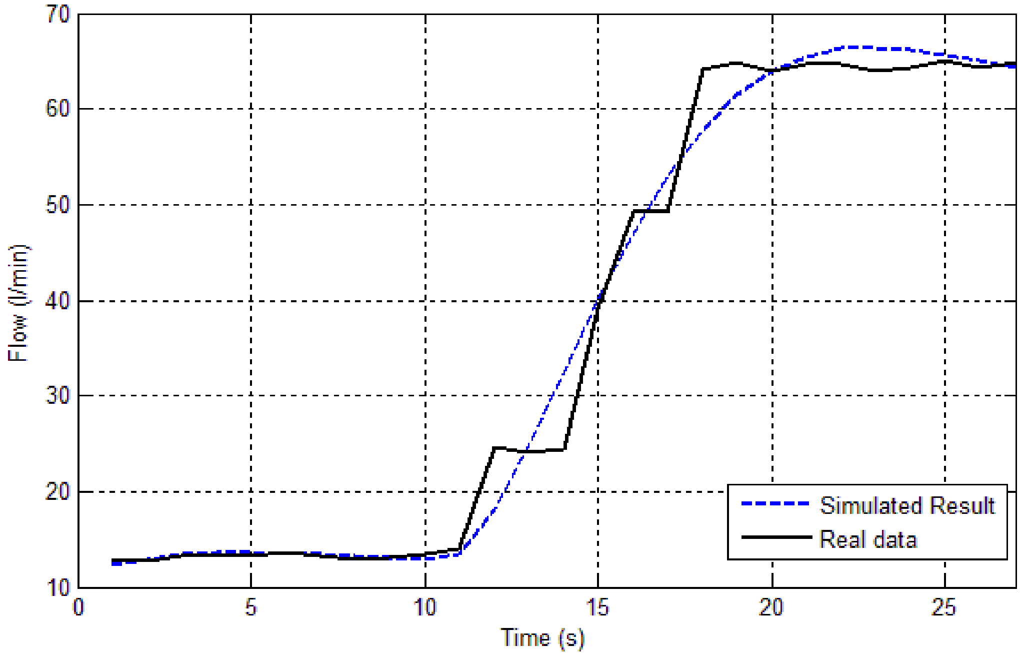

Figure 5. Identification and Validation of the Hidraulic System.

We conclude that the error presented was caused by the approximation of a Second Order System in a First Order System.

2.3 PID Controllers

According to PINTO (2014) 96% of the controllers that are in industrial environments is of the PID topology. PID controllers are composed of three actions with their respective gains, the higher the gain the greater the result of the action on the system response.

The equation governing the operation of the PID control is shown in 5.

$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}\right) \tag{5}$$

Where:

- Kp (Proportional gain);
- 1/Ti (Integral gain);
- Td (Derivative Gain);
- e(t) (Error);
- u(t) (Variable to be controlled).

According to BOJORGE-RAMIREZ (2015), the modes of action of the PID controller are described below:

- Proportional - accelerates the response of the controlled process;
- Integral - eliminates error, but produces slow and fluctuating responses;
- Derivative - anticipates future errors and introduces correction, also has stabilizing effect on the control mesh response.

Even with all these available actions, the application will not always require the three actions at the same time, the choice of action or the combination of actions depends on the behavior of the system to be controlled.

In Figure 6, the PI controller applied to the hydraulic plant is presented.

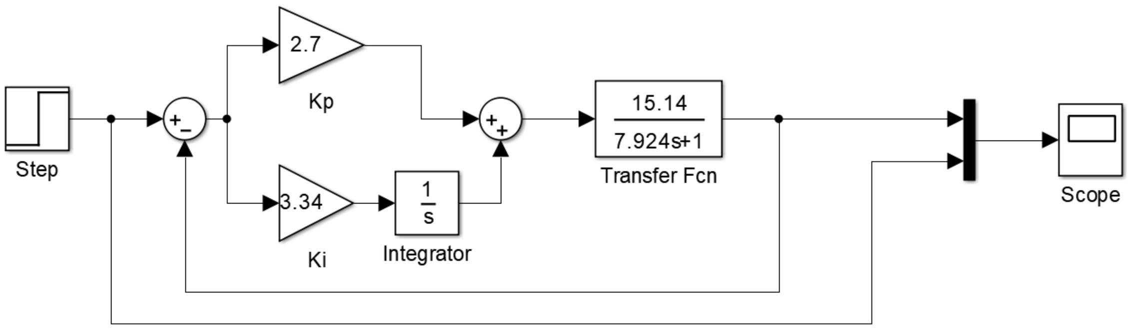

Figure 6. Block Diagram of the PI Controller

2.4 Fuzzy Controller

The interest in Intelligent Control Systems such as Fuzzy Logic, Neural Networks, Expert Systems and Genetic Algorithms, has grown substantially in the last decades. These systems seek to provide answers that solve problems, in a way appropriate to specific situations of the problem, forcing the control to adapt to new situations (SOUZA, 2012).

This work undertook to elaborate a Fuzzy Controller for the hydraulic system in question. The controller tests were performed in the SIMULINK Simulation Environment, as can be seen in Fig. 7. As a linguistic variable for input of the Fuzzy Controller, “error” for flow and “variation of error” of the flow were defined. The linguistic variable “error” is obtained by the value of SP and value of the VP. The linguistic variable “variation of error” is obtained by comparing the “error” in the current instant with the “error” in the previous instant. The “flow” of the motor was defined as the output variable.

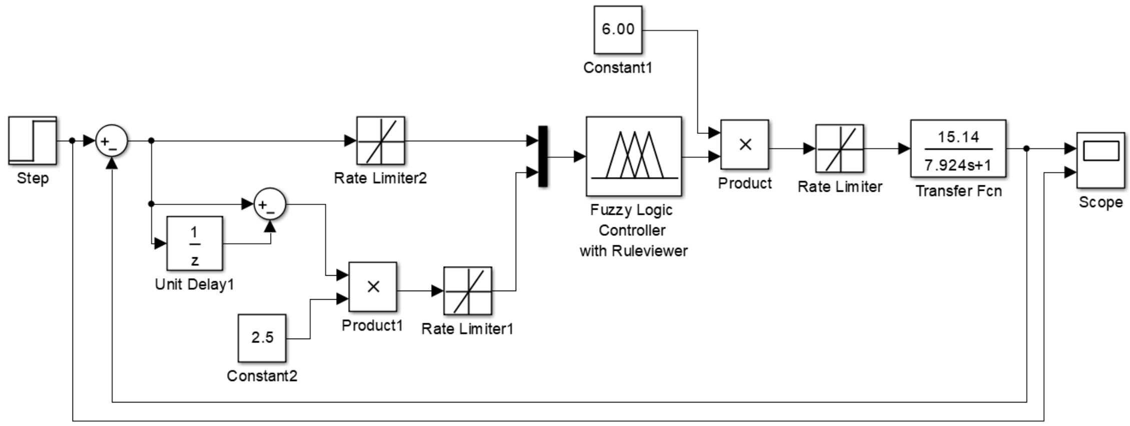

Figure 7 - Fuzzy Controller Block Diagram

The controller implemented in Figure 7, this is a digital Fuzzy-PI, this type of Fuzzy controller uses as base the conventional PI controller. The transfer function presented in the block diagram represents the System Plant identified in Equation 3. Rate Limiters are blocks that limit the first derivative of the signal (error variation) that passes through it. The output does not change faster than the specified limit. Already the counterparts are blocks of normalization gains that have been adjusted empirically.

This controller was designed with seven pertinence functions for the input variables 'error' and 'verro', as can be seen in Figure 8 and Figure 9.

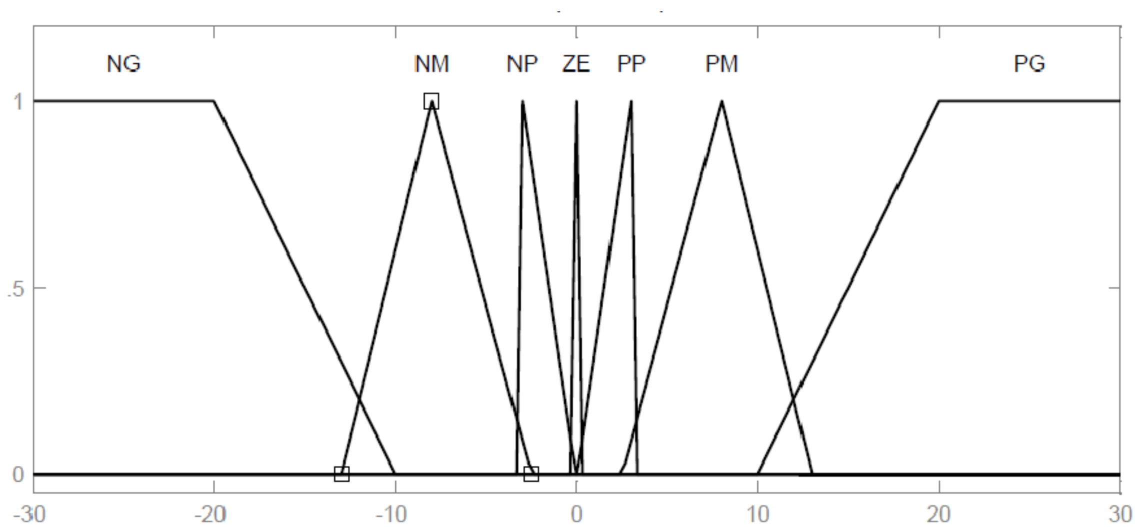

Figure 8 - Membership functions of the input variable 'error'

The use of the input variable 'verro' allows the controller to anticipate a corrective action, because when considering the error in the previous instant can perceive to where the values of the variable are tending, that is, when comparing the current value with the previous one the controller is able to perceive the increase or decrease of the error value.

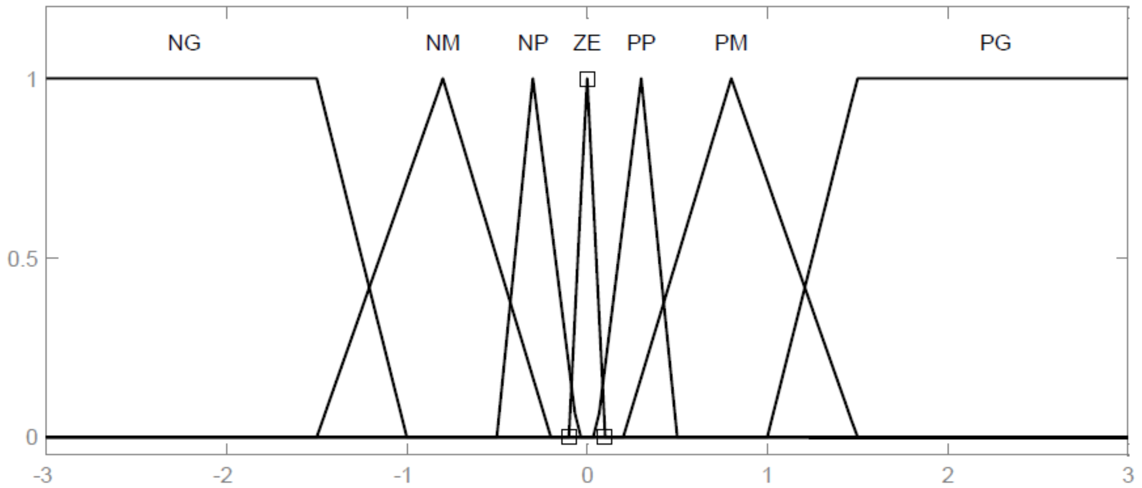

Figure 9. Membership functions of the “verro” input variable

For the output variable “flow” seven functions of pertinence were projected as can be seen in Fig. 10.

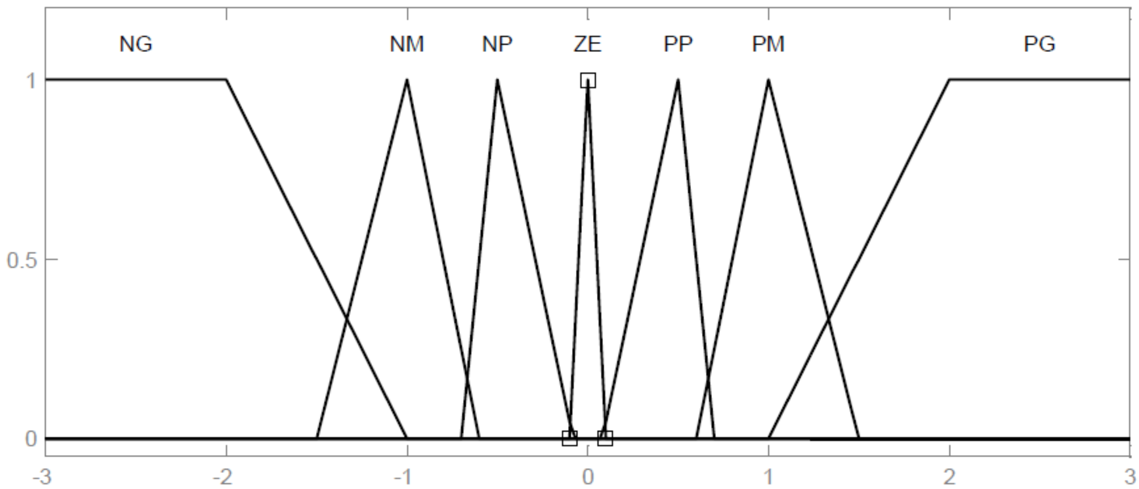

Figure 10. Membership functions of the output variable “flow”

With the functions of defined pertinence, the rule bases of the Fuzzy Controller were elaborated.

Table 1. Fuzzy Rule Bases.

e1 \ de1	NG	NM	NP	ZE	PP	PM	PG
NG	NG	NG	NG	NG	NG	NG	NG
NM	NG	NG	NG	NM	NM	NM	NM
NP	NM	NM	NM	NP	NP	NP	NP
ZE	NP	NP	NP	ZE	PP	PP	PP
PP	PP	PP	PP	PP	PP	PM	PM
PM	PM	PM	PM	PM	PG	PG	PG
PG	PG	PG	PG	PG	PG	PG	PG

The rule bases characterizes the control objectives and the control strategy used by specialists in the area, through a set of general linguistic control rules (SIMÕES & SHAW, 2007).

3 RESULTS

The PI and Fuzzy Controllers were implemented and simulated within the SIMULINK simulation environment of MATLAB (MATHWORKS, 2017). Fig. 7 shows the block diagram representation of the Fuzzy Controller. Fig. 11 and 12 show the graphs of the step response and the response to a square wave input for the Fuzzy controller.

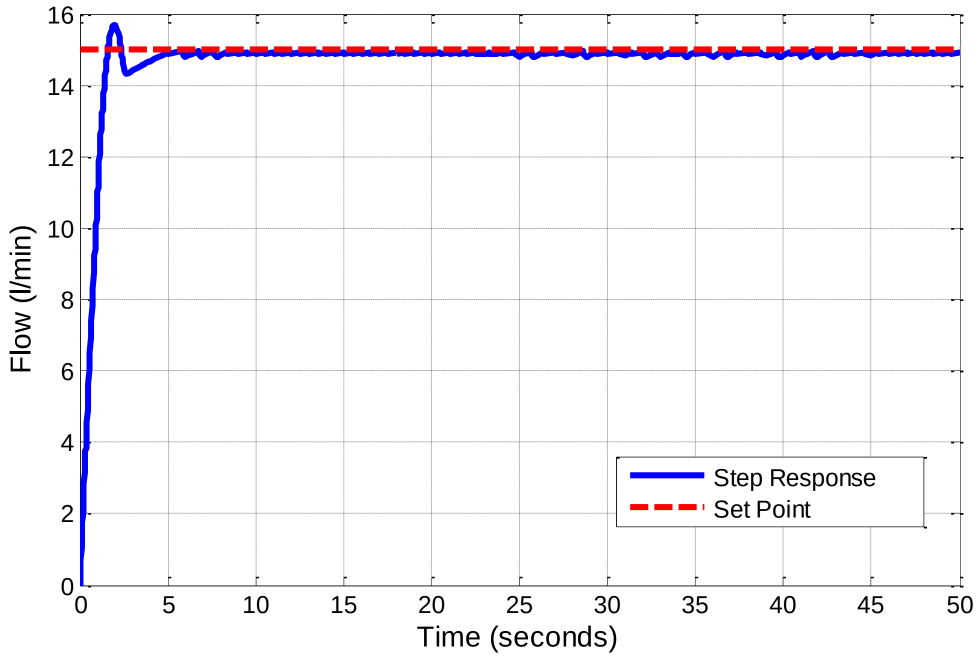

Figure 11. Response of the plant to the step with Fuzzy Controller

Note that the response of the Fuzzy controller presents low overshoot and reaches the setpoint with satisfactory speed.

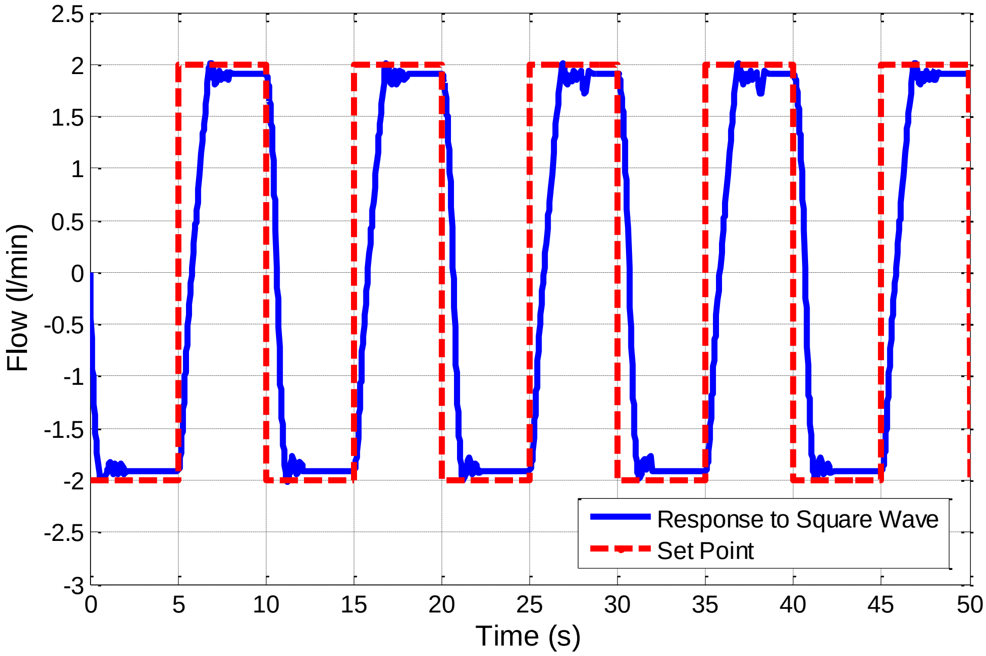

Figure 12. Response of the plant to a square wave

The response to a square wave produces an effect of sudden variation of setpoint, aiming to observe the behavior of the plant in these cases. In Fig. 12 the setpoint varies from 2l / min to -2l / min indicating that pump reversal occurs. Note that the system responds as expected based on the result shown in Fig. 11. However there is a small offset error present in the system response.

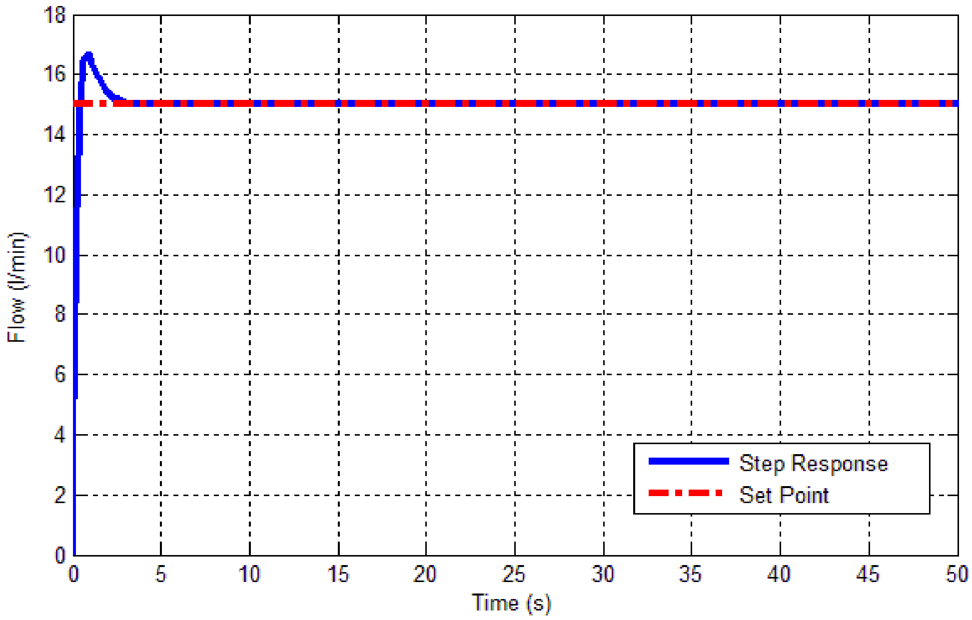

Figure 13 - Plant-to-step response with PI Controller

The response with PI controller also satisfies the step response quite satisfactorily and with high speed reaches the setpoint, however, a higher salient is observed in relation to the Fuzzy control.

Table 2 shows the results of transient responses obtained in the hydraulic system with the implementation of the PI Controller and the Fuzzy Controller.

Table 2 - Transient responses of PI and Fuzzy controllers.

	Controlador PI	Controlador Fuzzy
Tempo de atraso	0,13 segundos	0,87 segundos
Tempo de subida	0,41 segundos	1,6 segundos
Tempo de pico	0,86 segundos	2,0 segundos
Tempo de acomodação	4,1 segundos	4,78 segundos
Amplitude de pico	11,33 %	4,67 %

Although it presents higher times in relation to the PI controller, the Fuzzy controller presents very low overhang. This characteristic is interesting because smaller undershot indicates lower acceleration of the pump before stabilization of the desired flow. Therefore, with the minor overhang we have less impact, in relation to wear, of the mechanical elements of the pump due to the initial variation of the speed.

4 FINAL CONSIDERATIONS

Through the results demonstrated in this project we can say that the Fuzzy Controller, despite the delayed responses, is more appropriate.

These delays are small and become almost negligible taking into consideration the benefits produced by the low overhang.

The applications of control systems based on artificial intelligence depend on the functional knowledge of the system to be controlled, and on the actual verification of the advantages added with its use. Soon this work aims to make a simple contribution to the studies and implementation of intelligent systems.

As perspectives for future work, it is planned to investigate techniques of mathematical modeling of the plant in order to eliminate the offset error produced in the system response to square wave.

REFERENCES

Aguirre, L. A.. *Introdução à identificação de sistemas: Técnicas lineares e não-lineares aplicadas a sistemas reais*. 3. ed. Belo Horizonte: UFMG, 2007.

AMENDOLA, Mariângela; LUIZ DE SOUZA, Anderson; Barros, Laécio Carvalho, 2004, "*Manual do uso da teoria dos conjuntos Fuzzy no MATLAB 6.5*", FEAGRI & IMECC/ UNICAMP.

Bojorge-ramirez, Ninoska Isabel;. "Métodos Clássicos de Sintonia de Controladores". Disponível em: *http://www.professores.uff.br/controledeprocessos-eq/images/stories/Control_Aula16_Sintonia_1sem2015_v2.pdf*. Acess to 14 de june of 2017.

LUNA FILHO, Fernando de Melo, GOSMANN, Hugo Leonardo, BAUCHSPIESS, Adolfo, 2002, **“***Controle fuzzy para sistema de nível de líquidos”,* Natal, RN. Brasil.

Gambo A, S. S. A contribuição da pesquisa na formação docente. In: REALY, A.M.M.R.; MIZUKAMI, M.G. *Formação de professores: tendências atuais*. São Carlos: EDUFSCAR, 2003, p. 116-130.

MATHWORKS. Matlab. Versão R012b. Disponível em: *https://www.mathworks.com*/. Acess to: 12 de August de 2017.

National Instruments. “O que é aquisição de dados? ”. *Disponível em: http://www.ni.com/data-acquisition/what-is/pt*/. Acess to 21 of may of 2017.

Pinto, J. E. M. G.. *Aplicação prática do método de sintonia de controladores PID utilizando o método do relé com histerese*./ Jan Erik Mont Gomery Pinto. – Natal, RN, 2014 116 f. il.

Shaw, I.. SIMÕES, M. G. “*CONTROLE E MODELAGEM FUZZY*”, Editora Edgard Blücher Ltda. 2007.

Souza, Josué da Silva. *Implementação de um controlador fuzzy no simulink do matlab para um sistema de controle de nível*. João Pessoa: IFPB, 2012. 64 p. il.

Vale, M. R. B. G.. *Análise comparativa do desempenho de um controlador fuzzy acoplado a um PID neural sintonizado por um algoritmo genético com controladores inteligentes convencionais*. Dissertação de Mestrado em Engenharia Elétrica e de computação. UFRN, 2007.