DESIGN AND IMPLEMENTATION OF CONTROL OF LEVEL AND FLOW USING FUZZY LOGIC FOR THE INTELLIGENT CONTROL LABORATORY OF THE SURCOLOMBIANA UNIVERSITY

Agustín Soto O., Luz Adriana Guzmán T. and y Oscar Mauricio Calvache G.
Engineering in Industrial Control, Surcolombiana University Professor, Avenida Pastrana Carrera
E-Mail: agussoto@usco.edu.co

ABSTRACT

This work presents the design and implementation of a multivariable control for a hydraulic system. The work consists of two control variables common in the industry: Level and Flow, which are monitored in the main tank of the system. The development is made from the control algorithm performed by fuzzy logic on the microcontroller MC68HC912B32 Motorola instructions supporting this technique. It monitors the behavior of the variables wirelessly through the program developed in LabVIEW software for viewing on your computer. Previously recommended tests are made by manufacturers of engineered equipment and know their characteristics and the device used as the electronics, in order to achieve good performance of the plant and controller together. Finally, an analysis in terms of its operation and is obtained as a result the plant hydraulic laboratory practice for Intelligent Control of the course, physically and electronically structured monitoring of the variables corresponding to control, simplicity in the management presenting to can be used by teachers and students in the laboratory of Electronic Engineering program.

Keywords: control multivariable fuzzy logic, LabVIEW.

1. INTRODUCTION

Drivers that have been used for decades in different industrial processes are based on conventional control techniques, but as complexity increases, greater difficulty is found to define the most efficient technique to help to keep under control the process and optimize its performance. It is presented very often in Industry, plants where controlling must be held in more than one variable at a time, making it difficult to obtain a mathematical model as a result of nonlinear behavior that they may present, control will probably be much more rigorous by using conventional techniques and devices, which increase instability and cost for process control.

Since the first studies by Engineer Lotfy A. Zadeh in the mid- 60s at the University of Berkeley on fuzzy logic, it did not have much impact, but it was the starting point for the investigation of this technique. In the nineties it has great development and emerges as a control tool much more useful, based on the reasoning of the human being as the empirical knowledge of the process, it means, it does not require a mathematical model for the design. Some works done have been developed with traditional microcontroller or dsPIC as: fuzzy temperature control for resistive loads with 8-bit microcontroller, implemented on a general purpose microcontroller (Meneses, 2005), the design and implementation of a DC motor speed control using logic diffuse (Anzures, Ramirez and Guzman, 2007) or the design of a controller by fuzzy logic to a nonlinear prototype, which is based on the classical system of the ball and beam (BALL and bEAM) developed on a 16F family PIC microcontroller (Espinosa, Barahona, Villegas and Medina, 2008) which are projects developed in general purpose microcontrollers. The design of a fuzzy controller for a DC motor for the development of laboratory control and electrical power laboratory practices was one of the studios where dsPIC microcontrollers are implemented (Rodríguez, I. Lazaro, J. ANZUREZ, 2009).

Currently, there are two aspects that facilitate the implementation of a fuzzy controller, the first, is that in the market already exist specialized microcontrollers which have a set of specific instructions for that purpose and the second is the result of increased economy to the amount of electronic devices commonly used, however, at the local level, It has not been produced literature in the area of fuzzy controllers using Microcontrollers supporting fuzzy logic, at the national level is low and so is at international level, (Arias and Lemos, 2010) is one of the few applications where a microcontroller is used specially designed for applying fuzzy logic and It is done by controlling plants of second and fourth order giving good results. Thus this research is considered important because, not only is a contribution to building a broader base of knowledge with these types of devices but to implement the project is provided, the laboratory of the subject of intelligent Control with the hydraulic plant with strengthening the student learning program is provided.

2. METHODOLOGY

The implemented system has the ability to control the two variables: flow out of the main tank and the level thereof. For flow control a closed loop in which water flows from the control tank into the reservoir tank is implemented, its measurement is in charge of the Hall effect sensor located in the discharge line after the drain valve. Similarly, the level control is working in a closed loop, driving the fluid flowing from the reservoir tank to the main tank, for measuring the ultrasonic level sensor that is located in the top of the tank control is used. (See Figure-1) the system further has an additional tank located in the upper left with a valve which, when activated, allows the flow of water into the main tank, It is named as

Tank disturbance since it causes an external input in the plant.

Signals both the sensor, which indicates the amount of flow and the level sensor, which gives the needed information to determine the height reached by the liquid in the main tank, are taken to the conditioning step which are then received by the microcontroller which undertakes task control and ultimately to the wireless communication interface.

Two control schemes based on fuzzy logic algorithm with the help of a microcontroller are designed. This method of control to be smart can quickly develop a successful control, even when variables interact with each other, techniques can be used to separate or disengage the bonds of control variables; therefore, the fuzzy control is very useful for MIMO systems, the primary feature of this system.

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The user-level communication is possible through the interface designed in the LabVIEW program on a remote PC, there the user hovers the set point, this way, the practices performed on the floor of the Intelligent Control Laboratory of the Surcolombiana University will be more didactic and less complex.

Figure-1. Hydraulic plan implemented.

2.1. Hardware design

The center of the hardware fuzzy controller is the microcontroller, which in addition to have the programmed control algorithm also has at its periphery components and design of electronic circuits required to perform the tasks of the system for measuring the control variables , the adjustments to the actuators used and the communication.

2.1.1. Central control unit

This device is manufactured by Motorola, it is a microcontroller that has not been used in different program practices of Electronic Engineering, and therefore, its application in the project becomes interesting. The MC68HC912B32 16-bit microprocessor can also operate in a narrow mode of 8 bits to interact with a single 8-bit memory for lower cost systems. Their food is provided by the corresponding circuit with a 5V regulator, since its operating range is 5.5V to 4.5V and 8MHz. It has some key features that facilitate the implementation by reducing circuitry and contributes to achieve the major goal in the project, among them are: 32 kbyte EEPROM Flas memory, 1 Kbyte RAM, 768 bytes of EEPROM memory, CPU that supports fuzzy logic instructions (MEN, REV and WAV), has an analog to digital 8-bit converter (ADC), four channels for pulse width modulator (PWM), serial communication, including complementary. It is an 80-pin element with encapsulated surface mount.

2.1.2. Measurement systems to control variables (sensors)

The Plant has a digital ultrasonic sensor, which converts the signal variation of liquid level in a current signal of 4-20 mA. It has the ability to detect solid objects and liquids from a distance of 40.6 cm to a maximum of 10 m and is located on top of the structure just above the main tank.

Similarly, the system including a flow sensor responsible for detecting the flow amount flowing through the discharge pipe is based on the Hall effect where the turbine blades are of ferromagnetic material and each time they turn they pass close hall effect sensor generating a pulse. Depending on the speed at which the blades rotate, the sensor sends a signal proportional to the flow rate passing through these in a range of 2 to 243Hz.

Both the sensor signal level and the flow sensor are given in different units to be processed by the A / D converter built into the microcontroller, it is necessary to perform the corresponding conversion of current and frequency to voltage in the range of operation from 0 to 5 Volts.

2.1.3. Actuators (valves and electric pump)

Controlling the flow passage of both the main tank as the perturbation is performed using two solenoid valves, whose operation is based on the gradual adjustment of the coil current which when increased to its maximum value causes the valve to open fully. Flow range is 0.5 to 12.7 m3 / h which cover the need for required capacity. Disturbance to the tank an ON - OFF system is operated and the main tank requiring more control system

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is operated proportionally. After the D / A converter to do its processing, you must include a converter that takes operating range of 0 to 5 Volts at a current signal 4 to 20 mA, which is the final control signal for the two valves.

The pump used is electro-submersible type, because it has the reservoir without any discharge port. Its range is from 24V to 27.2V and open flow consumes 1.4 Amp and 2.0 Amp 24V to 27.2V and pumps 4164 liters per hour discharge 1", however, a ½ inch fitting is performed for the purpose of connections to system piping.

2.1.4. Wireless communication

To reduce the necessary connections for the plant to directly communicate with the computer where the student or teacher works, it uses wireless communication. The Xbee modules are used in this project for the transmission of data, being the most appropriate alternative, in terms of economy, speed and easy implementation. Power is required for a device that regulates the input voltage to 3.3 volts so as not to have problems with the operation.

2.2. Software design

2.2.1. Code warrior

Code Warrior HCS12 (X) Special Edition software for programming the special microcontroller is used. One of the great advantages of this software is that it allows simultaneous programming of different programming languages, however, the C language for general settings and the specific modules of the microcontroller are handled: the analog-digital conversion, asynchronous communication serial and PWM. Moreover, for programming controllers assembly language is used, because the instructions needed to use the fuzzy module are not available in C language the microcontroller code is developed in three stages: the main program, fuzzy controller to manage the power of the electro-submersible pump and a fuzzy controller to manage the opening of the drain valve.

2.2.2. Interface in LabVIEW

To be established the hydraulic plant in the Intelligence Laboratory management; interactive interface that makes understanding the process by the user is developed. The interface on the LabVIEW software has two controls to enter the Set Point (or desired value) of each variable, two graphs with numeric display for better visualization of the behavior and the point reached by the variable Level and Flow and a third control to select the port for which task is to communicate with the plant. It has two buttons, a first for the empowerment of disturbance (related to the opening or closing of the tank valve disruption) and a third button to stop the process at any time (STOP). Finally, a graphical representation of the plant consists of tanks blocks, valves and sensors deployed in the project using the DSC module (Dataloggin and Supervisory Control) as a practical tool for monitoring system. Each of these elements can be seen in Figure-2.

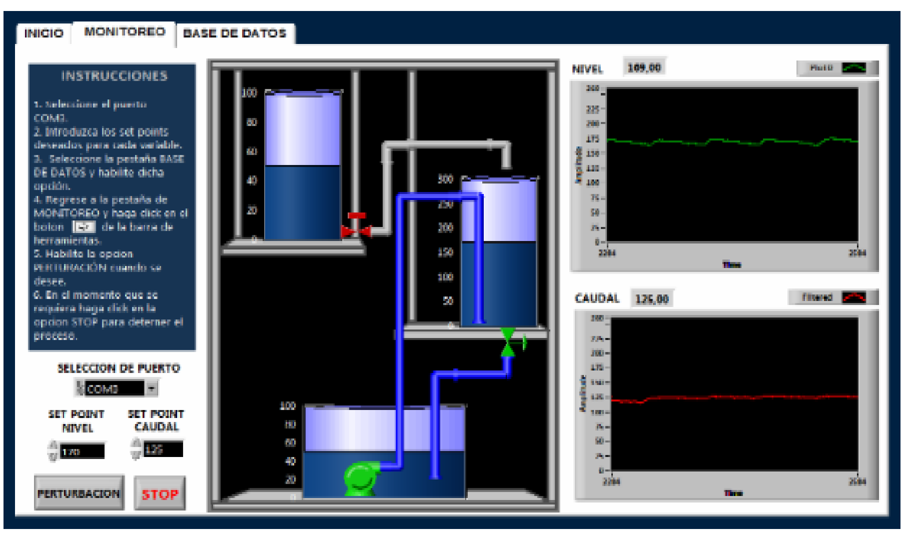

Figure-2. Monitoring panel in LabVIEW.

In Industry is carried out not only monitoring of the behavior of control variables but also the recording of information in databases. Therefore, a second panel has a button that enables the writing of data acquired in a certain time, with this, the ability to store and display the data both variable level as the flow variable is available in a database that is stored in the computer as a notebook, which location and name is chosen by the user (See Figure-3).

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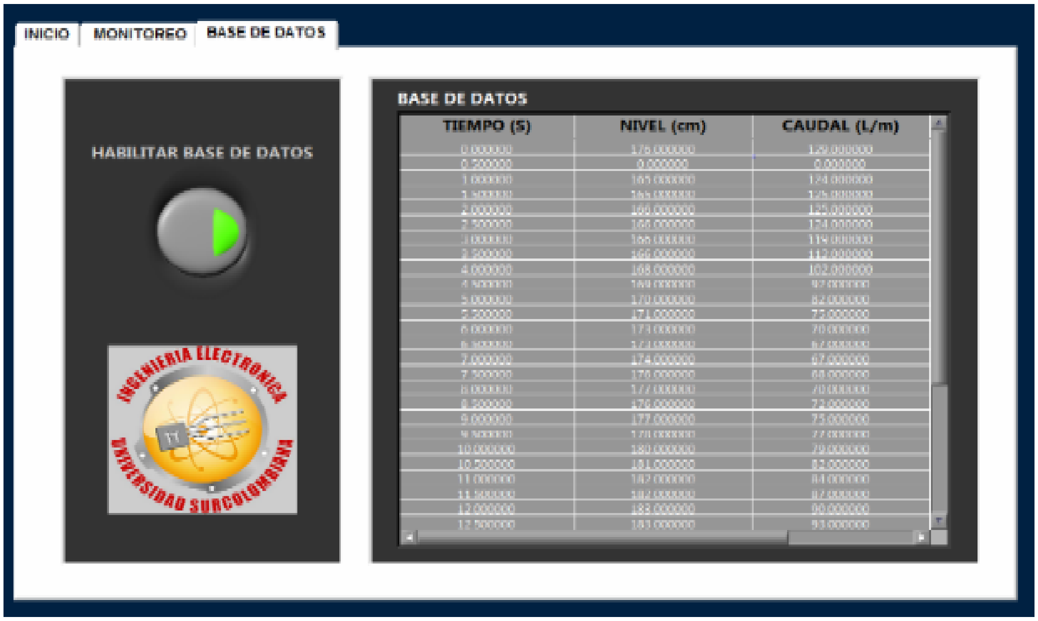


Figure-3. Database panel.

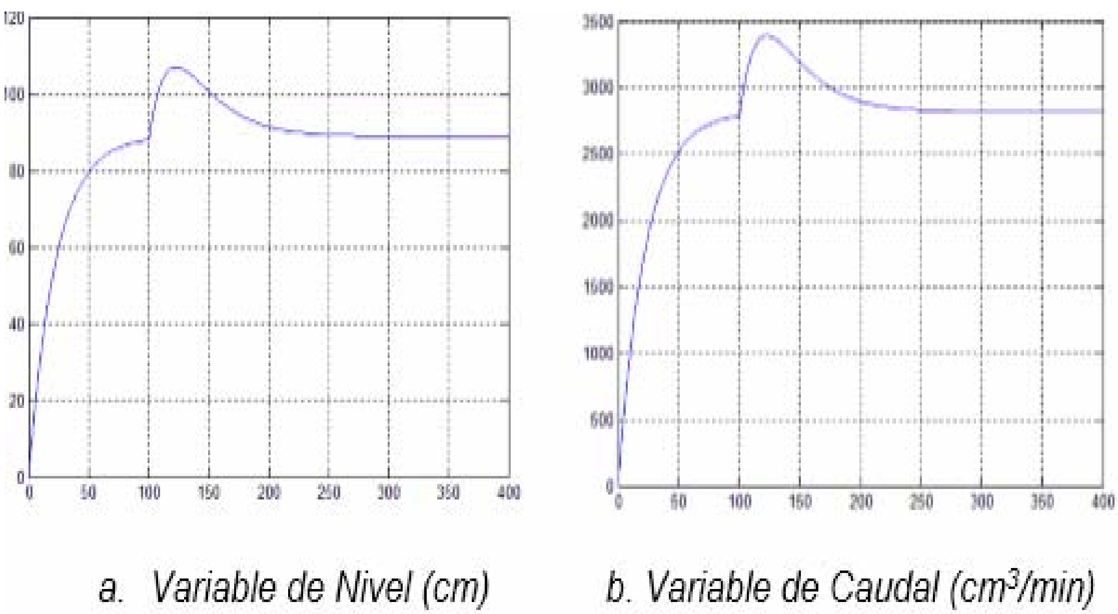
3. RESULTS

3.1. Model and simulation

One of the main advantages of implementing a fuzzy control is not necessarily have the exact model of the plant to be controlled (Banks and Hayward, 2001), however, the behavior of the hydraulic plant is not as complex and it is obtained the approximate model. Equation (1), which includes the tank capacity to be controlled and the voltage applied to the pump and the drain valve.

$$C*\frac{dh}{dt} = 1393.4*V_B - \frac{h}{0.126*e^{-0.277*V_v}} - 11114 \quad (1)$$

The model is used to perform the corresponding simulations and to make the corresponding adjustment of the variables to be controlled. In Figures 4 (b, to the level variable and b to the flow variable, respectively) the graphs were obtained by developing the simulation taking into account the system perturbation, in the MATLAB software.



Level variable **b. Flow variable**

Figure-4. Simulation.

For this simulation the perturbation begins after 200 seconds after the system becomes operational. It is clearly seen that the tank level rises for a moment of time, which also produces a change in the outflow. When the disturbance flow begins to decrease due to the lack of liquid in the tank of disturbance, the system tends to stabilize again because the outflow is greater than the input at that time.

3.2. Fuzzy logic

A multivariable controller is developed leveraging techniques fuzzy control, since it allows the description of the physical system using empirical knowledge of the process to be controlled and sets and own rules can be designed to achieve high approximation obtaining the optimal results in practice. It works with the MATLAB software to facilitate the design.

3.2.1. Fuzzification

The fuzzy control system has two input variables, where the first is error level and the second is the flow error. Each variable is calculated as the difference between the measured value and the desired value. The variables quantify how far or close it is to the desired value or Set Point. The error level has been characterized with the following linguistic values: low, good and high. To quantify the degree of membership of these sets, their membership function are defined, which specifies the values of the variable error level and with what degree, as shown in Figure-5.

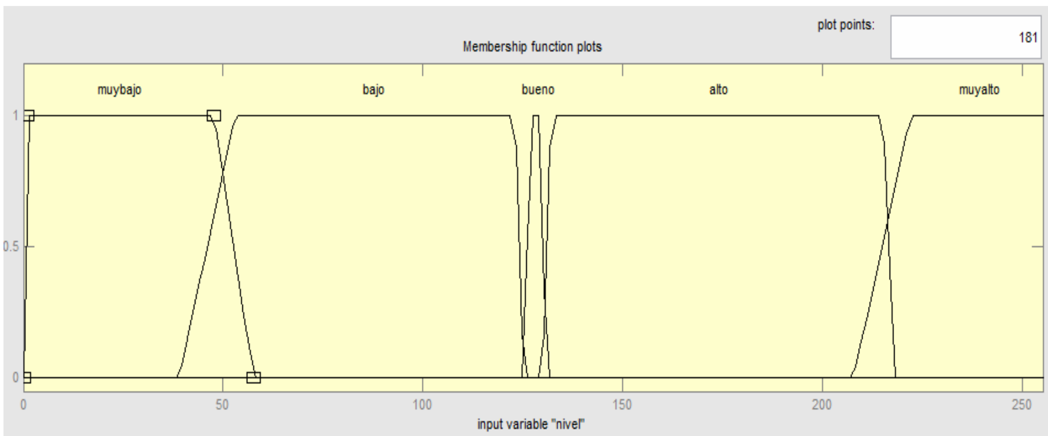


Figure-5. "Error level" linguistic values.

The second variable, the flow error is characterized with tags: very low, low, good, high and very high. The membership function for each set shows which values of the flow error belong to them and with what degree, similarly, can be observed in Figure-6.

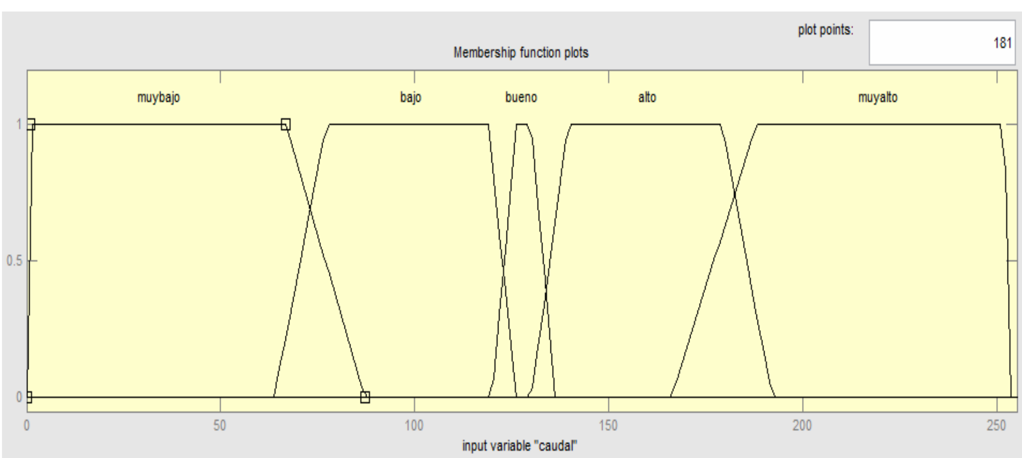


Figure-6. “Flow errors” linguistic values.

3.2.2. Inference (Evaluation of rules)

The next step is for setting the rules, assess their background and obtain the degree of truth for each. The fuzzy control system processes rules of style: SI “antecedente1” and “antecedente2” is.... THEN consequent. The 15 rules that control the system are written with judgment and common sense based on human reasoning (Brubaker, 1992) and knowledge of the plant, in

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this way, they are shown in Table-1 for the output variable "PWM Bomba" and Table-2 for the output variable "Open valve" in the control tank.

Table-1. Matrix Rules for PWM of the submersible pump.

PWM BOMBA					
NIVEL / **CAUDAL**	**MUY ALTO**	**ALTO**	**BUENO**	**BAJO**	**MUY BAJO**
MUY ALTO	Apagar	Apagar	Medio	Medio alto	Alto
ALTO	Apagar	Apagar	Medio	Medio alto	Alto
BUENO	Apagar	Apagar	Medio	Medio alto	Alto
BAJO	Apagar	Apagar	Medio	Medio alto	Alto
MUY BAJO	Apagar	Apagar	Medio	Medio alto	Alto

Table-2. Matrix of rules for opening the drain valve.

APERTURA VÁLVULA					
NIVEL / **CAUDAL**	**MUY ALTO**	**ALTO**	**BUENO**	**BAJO**	**MUY BAJO**
MUY ALTO	Cerrar	Cerrar	Cerrar	Cerrar	Abrir
ALTO	Cerrar	Cerrar poco	Cerrar poco	Cerrar poco	Abrir
BUENO	Cerrar	Mantener	Mantener	Mantener	Abrir
BAJO	Cerrar	Abrir poco	Abrir poco	Abrir poco	Abrir
MUY BAJO	Cerrar	Abrir	Abrir	Abrir poco	Abrir

For the output variable "PWM Pump" 4 tags are defined: Off, medium, high and medium high, which can be seen in Figure-7. Similarly for the output variable "Open Valve" 5 labels are characterized with: “close, close enough, maintain, open slightly and open” showed in Figure-8. The type of fuzzy controller is proportional because, it is taken only the current values of the error of each variable.

In practice a MC68HC912B32 microcontroller is used, the device handles diffuse instructions and for calculations it uses singleton output functions. When handling fuzzy control simulation in Matlab software, the output functions were taken from the triangular type, because this program does not handle the operated for the integrated.

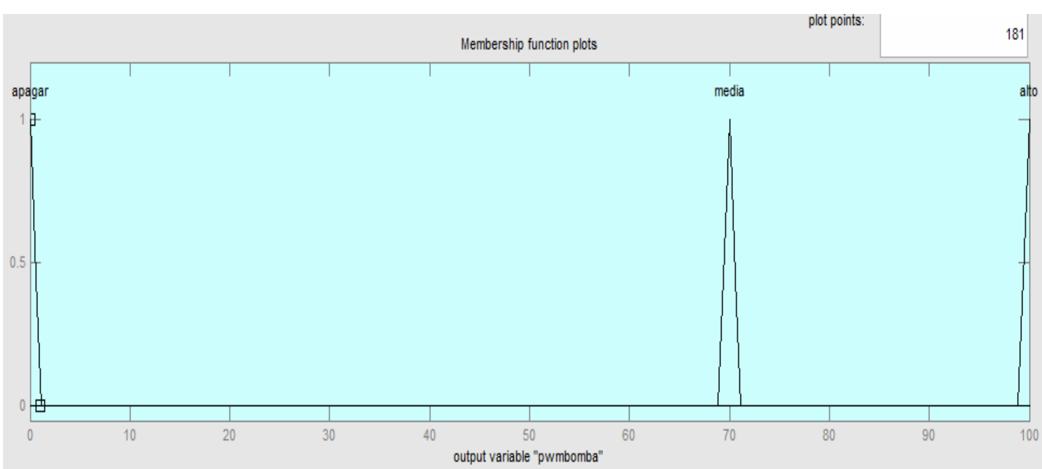

Figure-7. "PWM pump" tags.

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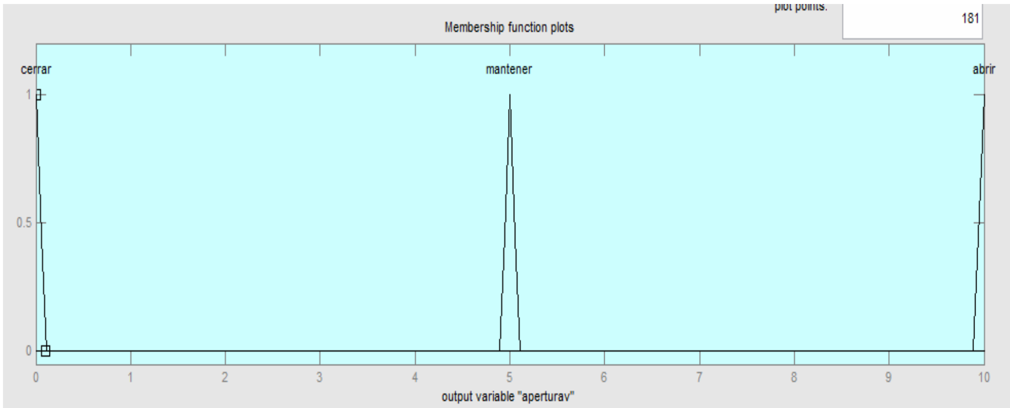

Figure-8. "Open Valve". Tags.

3.2.3. Defuzzification

With the values obtained in the inference process, the output of the system is calculated, is the final step, where fuzzy values are converted into control signals for the plant. These values are calculated as the weighted average of the fuzzy outputs, using Equation (2).

$$Salida = \frac{\sum_{i=1}^{n} S_i F_i}{\sum_{i=1}^{n} F_i} \quad (2)$$

Where:

n is the number of output functions.

S_i is the singleton positions knowledgebase
F_i are fuzzy values calculated

3.3. Controller response

Once fully implemented the system, we proceed to evaluate the performance of multivariable fuzzy controller for the hydraulic plant. A large number of tests were performed with different set points for each variable, where parameters can be identified such as settling time, steady state error and overshoot that will determine if the controller responds satisfactorily. In Table-3 the results of 4 tests are shown.

Table-3. Tests and results of multivariable controller.

Prueba	Variable	Set Point	Perturbación	Tiempo de establecimiento	Error en estado estacionario	Sobreimpulso
1	Nivel (cm)	25	NO	70 seg	3%	4 %
	Caudal (cm^3/min)	3000	NO	75 seg	1.75%	12%
2	Nivel (cm)	10	NO	57 seg	2 %	3 %
	Caudal (cm^3/min)	1500	NO	68seg	1 %	11 %
3	Nivel (cm)	15	SI	31 seg	0.6 %	6 %
	Caudal (cm^3/min)	2000	SI	74 seg	0.5 %	3.8 %
4	Nivel (cm)	20	SI	40 seg	1 %	3.5 %
	Caudal (cm^3/min)	2500	SI	82 seg	0.75 %	7.4 %

It can be corroborated the driver response curves obtained in the 4 tests. In Figure-9, for the variable level, we see that the overshoot is almost zero and once the transitional arrangements ended Level value entered by the user from the PC with a steady-state error of ± 0.3 is reached cm on average.

On the other hand, for variable flow in Figure-10, the response where there is a considerable overshoot but also for this variable is displayed, the settling time decreases remarkably and it is achieved the desired value by the user with a stationary error of ± 30 cm^3/min on average.

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For tests 3 and 4 where the disturbance is enabled greater change is not observed despite being an external input of liquid it has not greater influence on the behavior of the plant.

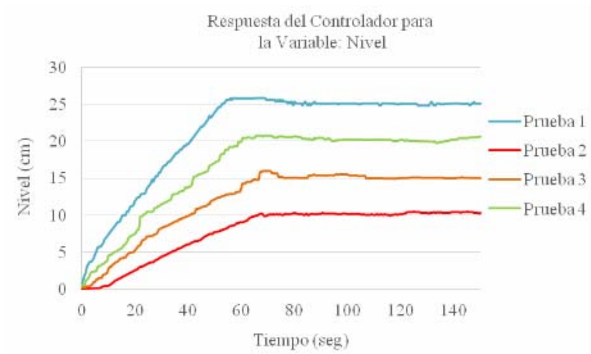

Figure-9. Controller response: variable level.

Figure-9. Controller response: variable flow.

4. CONCLUSIONS

The study has been presented successfully, the design and implementation of Multivariable Fuzzy Controller hydraulic plant, which allows carrying out the practices of Intelligent Control subject of the programme of Electronics Engineering.

Although obtaining the mathematical model that describes the behavior of the plant has not had more complexity and the response of fuzzy controller was optimal, there are plants in the industry to which they should invest more time in making the appropriate model, this, one can say that the control through fuzzy techniques is one of the most appropriate to address the problem.

It has facilitated the work to develop the controller with the microcontroller that supports fuzzy instructions, as it presents a great advantage in terms of speed and efficiency in the processing time of the rules, however, its disadvantage is the cost to be cheaper a conventional microcontroller but implementation represents slow and low precision in your answer.

LabVIEW is the software that provides different options for programming practices, as an innovation is incorporated into the developed interface, the application of DSC module that allows students or teachers to monitor the process interactively.

The development of a wireless communication using Xbee modules ensured not only the reliability of data transmission, but the reduction of the wiring for connecting the ground with the computer.

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