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Different Design Approaches For The Implementation Of A Hysteresis Window Control System

J.G. González-Hernández[1,2], V.H. Trinidad-Puente[3], J. Zamora-Santiago[3], R. Castillo-Gutiérrez[1]
Tecnm Campus Instituto Tecnológico De Ciudad Madero, México
Universidad Tecnológica De Altamira, México
Tecnm Campus Instituto Tecnológico De Cerro Azul, México

Abstract :
It is well known that in many control applications, the hysteresis can be taken advantage of to provide an easy and accurate solution for control purposes. In this paper, the automation of a hysteresis window controlling system is presented. Different solutions, such as classical digital control, block diagram functions, ladder diagrams, and on-off relays' modules, were implemented by engineering college students, showing students' interest and establishing a solid foundation for their technical training and understanding of automatic control techniques.

Keywords: *Control Systems, Hysteresis, Digital Systems, Blocks Diagrams Functions, Programmable Logic Controllers*

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I. INTRODUCTION

In the field of automatic control systems, maintaining stability, precision, and responsiveness is crucial for ensuring reliable operation. One fundamental concept that significantly contributes to this goal is the hysteresis window. Hysteresis refers to the dependence of a system's output not only on its current input but also on its past behavior. The hysteresis window, specifically, is the defined range within which an automatic system does not react to changes in input, thereby preventing frequent and unnecessary switching. This is particularly important in systems where rapid or oscillatory transitions between states can lead to inefficiencies, wear, or instability. By incorporating a hysteresis window, control systems (such as thermostats, motor controllers, or feedback loops) gain resilience against minor fluctuations, reduce system noise, and enhance performance by introducing a controlled delay in response. Consequently, understanding and designing appropriate hysteresis windows is vital for optimizing automatic control systems across various engineering applications [1-9].

In the study and application of control systems, presenting different solution options is essential for both effective system design and educational development. From a technical perspective, exploring various control strategies (such as ladder diagrams, classical digital control, block diagram functions (BDF), or on-off relays' modules) enables engineers to evaluate trade-offs between complexity, performance, robustness, and cost. For engineering students, this multiplicity of options fosters critical thinking, creativity, and problem-solving skills [10-18].

By comparing alternative solutions, students gain a deeper understanding of system dynamics, design constraints, and implementation challenges. This approach also mirrors real-world engineering practice, where professionals must assess several viable paths before selecting the most suitable one based on specific system requirements. Furthermore, exposing students to different methods enhances their adaptability and prepares them to make informed decisions when faced with evolving technologies and diverse application scenarios. Thus, presenting multiple solution options not only strengthens the design process but also plays a vital role in the teaching-learning experience in control systems engineering. Nowadays, it is very common to find projects which have been developed to present different solutions to face control automation systems [19-23].

II. DYNAMIC MODELING

Let consider the specific case of the following tank-water level control with a double hysteresis window (Fig. 1). The system contains three electrodes in the tank and three more in the cistern. The lower electrodes are connected to the power supply, so the water closes the circuit by making contact with the middle and upper electrodes, allowing the programmable relay to detect a logic 1 on its corresponding inputs. In the case of the water tank, when the water stops making contact with the central electrode, the pump must start and remain on until it makes contact with the upper electrode, at which point it stops. Then, once a logic 0 is reached on the upper electrode, the system remains off until the lower electrode reaches zero, and the sequence repeats. Of course, all of this occurs normally as long as the safety hysteresis window associated with the tank grants permission.

In the case of logic control of the lower tank, if the upper electrode sends a logic 1 to input I3 of the programmable relay, then the lower tank is full and grants permission for the system to operate normally. If I3 then becomes logic 0, the lower tank's permission remains active; however, if I4 becomes 0, permission is denied until the liquid level reaches the upper electrode again, ensuring system safety and preventing the pump from operating in void.

As it can be seen, Table 1a represents the true table for controlling the pump (output Q1), without considering the lower tank permission (M1). The Table 1b shows the true table for the lower tank hysteresis window, which is responsible for the system's security, since it keeps the pump from working in void. The Table 1c describes the relationship between the inputs/output of the controller and the physical components.

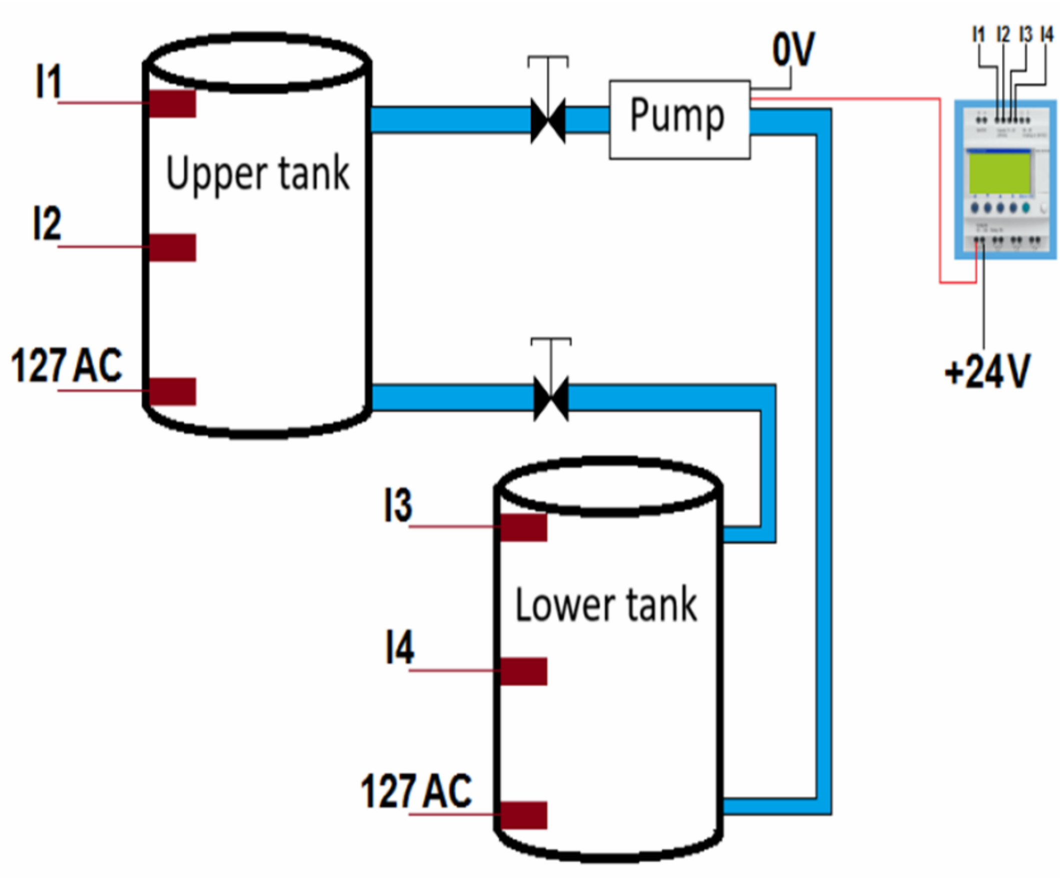

Figure 1. Tank-water level control system

Table 1. Hysteresis window for the: (a) pump, (b) lower tank permission. (c) Relationship between the inputs/output of the controller and the physical components

Table 1a			Table 1b			Table 1c	
I1	I2	Q1	I3	I4	M1	Element	Description
0	0	1	0	0	0	I1	Upper sensor of upper tank
0	1	Q1	0	1	M1	I2	Lower sensor of upper tank
1	0	X	1	0	X	I3	Upper sensor of lower tank
1	1	0	1	1	1	I4	Lower sensor of lower tank
						Q1	Control output for the pump

III. BOOLEAN ALGEBRA EQUATIONS

Let us consider Table 1a to obtain the correspondent output equation for Q1 using mini terms methods as it is shown in Eqs. (1-3)

Now, this is partially the equation for Q1, but the lower tank permission (M1) must be considered for security reasons, then, rewriting Eq. (3), Eq. (4) is obtained:

Now, let's consider Table 1b to obtain the logical equation for M1, as it is shown in Eqs. (5-7)

Then, rewriting Eq. (4), the final algebraic Boolean equation for Q1 is obtained, as shown in Eq. (8)

IV. RESULTS

In order to implement the on-off control system, four approaches were presented:

1) Ladder diagram. Fig. 2 shows the ladder diagram proposal using Zelio SR3B101FU programmable relay. It is important to establish than this is the most common PLC language, so it provides a very well-known platform for solving the problem.

Rows number 3 and 4 represent the combination of the contacts to obtain the output Boolean equation for M1, as shown in Eq. (8). It is important to mention that in this software, the lower-case letters are used for the representation of the normally closed contacts (inverted inputs/outputs). For instance, .

The rows number 1 and 2 are the contacts combination for representing the logical equation for the pump (Q1). The contact M1 responds according to the coil M1 at the end of the row number 3. The performance of ladder diagram was verified in the simulation mode as shown in Fig. 3.

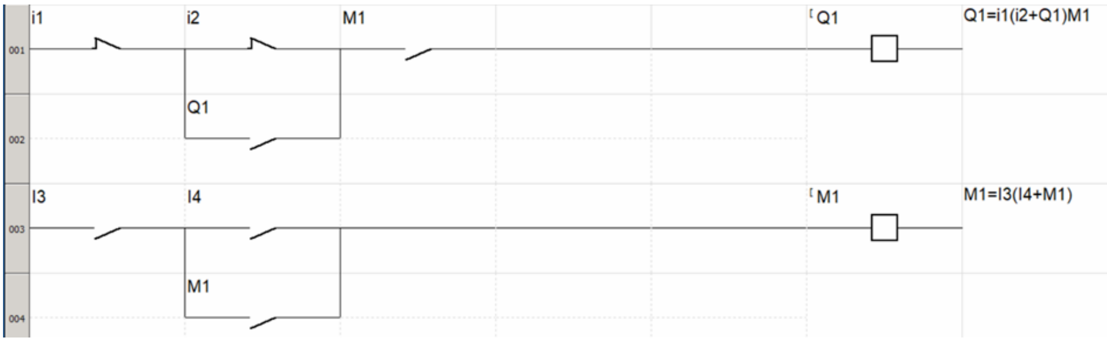

Figure 2. Ladder diagram implementation

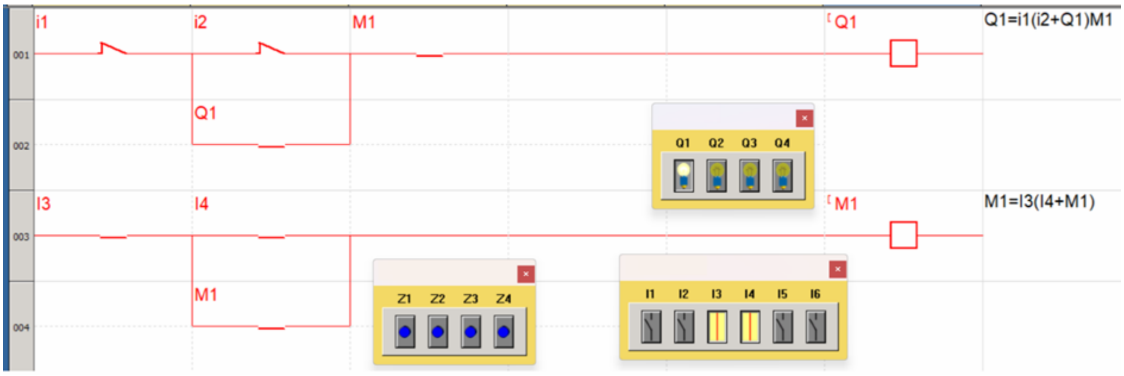

Figure 3. Ladder diagram simulation

2) Block diagram functions. Fig. 4 shows the BDF proposal using Zelio SR3B101FU programmable relay. Probably this is the most versatile PLC language, so it provides an excellent option for solving the problem.

This option provides logical gates to program the system, the interconnections and feedbacks for M1 and Q1 can be seen in Fig. 4, as well as the simulation in Fog. 5. All the possibilities shown in the true tables were verified.

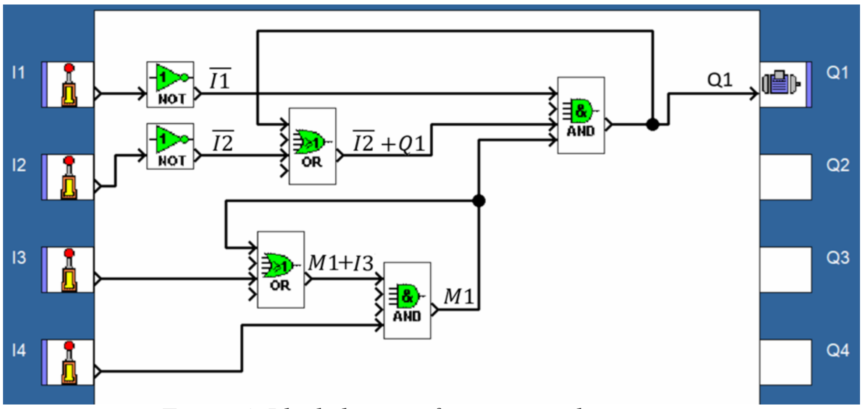

Figure 4. Block diagram functions implementation

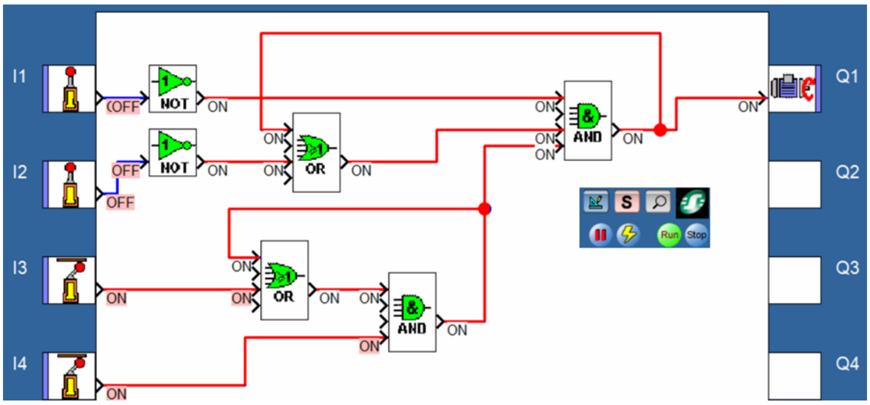

Figure 5. Block diagram functions simulation

3) On-off relays' implementation. Fig. 6 shows on-off relays that can be configured by setting the central voltage and the hysteresis voltage by the selectors. In this case, acoustic level sensors were used to measure the level. The correspondent output values for the upper and lower threshold voltage were obtained and then, the central and hysteresis voltages were calculated to configure the on-off relays. Of course, a PID controller can also be used in case a complete control level system is implemented. The contacts of the relays are directly controlled according to the settings configured in the module.

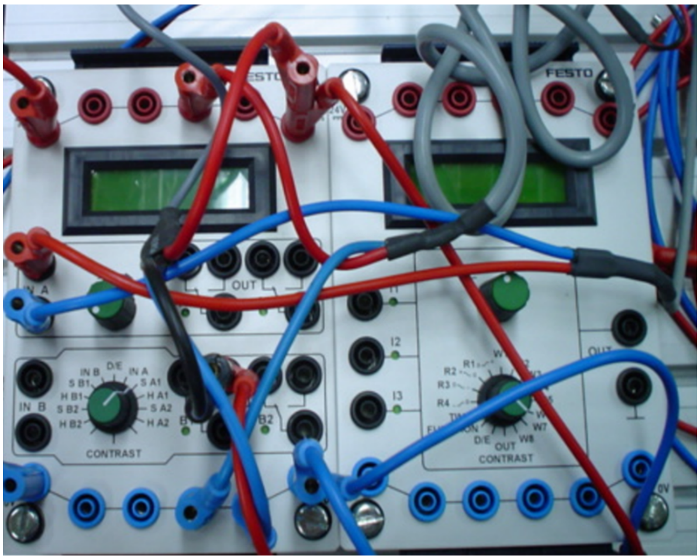

Figure 6. On-off relays' implementation

4) IC logical gates physical circuit: Fig. 7 shows a model in Tinder CAD platform for the physical circuit implementation using TTL logical gates.

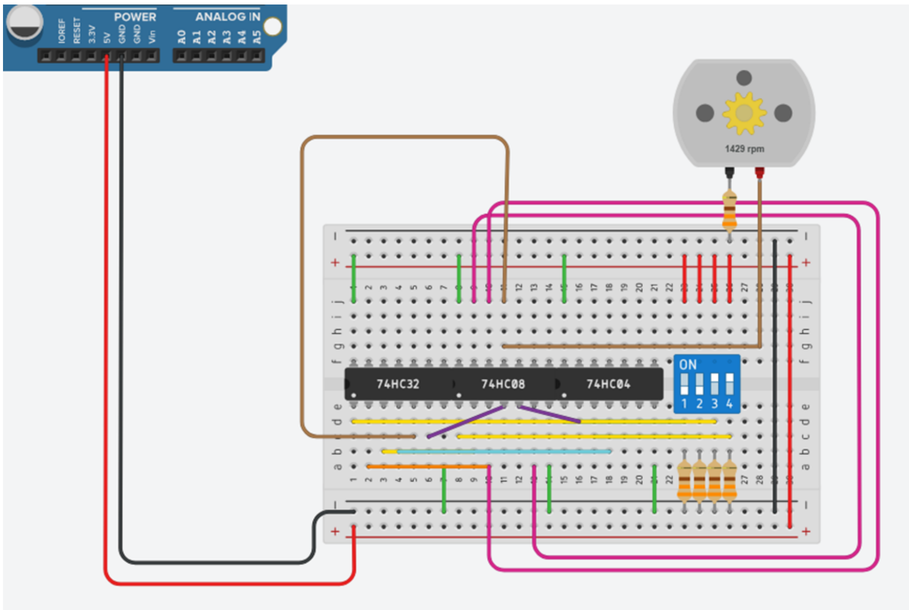

Figure 7. Integrated circuit logical gates implementation

V. FINDINGS AND COMMENTS

The different approaches were verified in simulation and also in the physical implementation. The use of the Zelio programmable controller in both, ladder diagram and BDF provided an easy and fast way to solve the automation problem, but it is an expensive alternative. The use of on-off relays provides also an easy implementation alternative, nevertheless, it needs a sensor to deliver a voltage proportional to the upper and lower-level limits and it is not a cheap option. Finally, the integrated circuit gates digital option is the cheapest, since it only needs a simple relay to be connected to provide the power the pump, nevertheless, it requires more time for the connections.

VI. CONCLUSION

This work provided different options to solve an automation system, taking advantage of a hysteresis window. Approaching an automation engineering problem from multiple perspectives offered significant advantages in both professional practice and engineering education. Technically, it allowed future engineers to explore a range of potential solutions, leading to more robust, innovative, and efficient designs. Each point of view (whether mechanical, electrical, software-based, or systems-oriented) can reveal unique constraints, possibilities, and optimizations that may not be apparent through a single-discipline lens. This holistic analysis enhances system integration, reliability, and adaptability in real-world industrial settings.

Furthermore, this multi-view oriented automation solving problems method was successfully tested and verified in engineering students in three different superior educational institutions, thanks to our teamwork.

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