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Speed Control of a current Motor Continues Using The PI Controller An Arduino Uno Microcontroller

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---***ABSTRACT***---
In this article, the development of an integral proportional controller (PI) is carried out, through the use of a microcontroller in order to always keep the speed stable for a direct current (DC) motor-generator system with which it counts. laboratories. For this, two stages were developed, the first involves the control stage, it consists in the development of the circuit of the ARDUINO UNO R3 board, where the PWM signal and the signal from the analog-digital converter are present, at this stage the code is made programming, which was carried out with the configuration of the PI controller, as well as the acquisition of analog signals and the emission of digital signals. The second stage is the power stage in which the power circuit, the DC motor, are immersed. in addition to the transducer. In this second stage the tuning of the speed regulator is carried out by the Ziegler-Nichols method, the stability of the machine is obtained by the trial-and-error method from the values calculated by the previously mentioned method. The speed set as a reference is 2000 revolutions per minute (rpm), either under load or idle.
KEYWORDS;- *Proportional Integral Controller (PI), PWM, ARDUINO microcontroller, DC motor-generator, speed control.*

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I. INTRODUCTION

One of the most common problems of DC motors is to maintain a constant or stable speed which is of utmost importance in the production processes in industries or with applications of automotive vehicles among others, these alterations can be produced before disturbances of conditions at full load or empty, that is why decision is made to implement a PI controller. Nowadays, in addition to knowing an exact control method, it is important to have knowledge of DC machines. since it is necessary to know and manipulate the electrical and mechanical parameters, in addition to having knowledge of which are the parts that make it up and how they function within the system. Previously, manual control was used according to the criteria and needs of the operator, although they were not always completely accurate, which led to inaccurate operation. Due to technological advances, the need arises to implement a controller with the ability to select an optimal operation of the machine, there are multiple methods for controlling DC motors. ranging from the typical electromagnetic control and control by PLC'S, on the other hand there is control by means of power electronics that replaces the previous equipment, however the first two although they are robust are very expensive, the third does not manage to be completely efficient in very complex processes begins to have problems that is why the need arises to implement a control based on microcontrollers, as is the case of the ARDUINO UNO R3 electronic card in which a series of instructions necessary to develop multiple types can be programmed of control.

The implementation of the automatic control system is carried out to establish a reference speed at which the controller will always seek to remain through feedback, where despite being subject to sudden load changes (under load or empty) It is regulated and always maintained at its reference speed previously established in the programming code for a microcontroller. The DC motor is used, in connection of independent excitation, for the reason of being the motor with the greatest possibility and stability in the control of its speed. The PI controller is widely known as a classic type of control, in which two types of regulators are used, such as the proportional regulator which acts instantaneously and the integral regulator, which acts in a time interval. This type of controller is implemented to be used as a support and reference for school development and even with the purpose of being implemented in industrial or commercial control systems. Where it is mentioned that the developed programs can be used for any purpose or with any computer system, in addition to the freedom to study the internal operation of the program to be able to adapt it to the user's needs and to be able to distribute the copies that are considered necessary. , but the most important is for the community that develops in the programming code has the ability to contribute and provide useful advice to improve the programming environment [1]. With the technological advances that are presented today, the use of induction motors has increased because they have the advantage of economic maintenance, and the power supply is what is available in the national electrical system. Even so, in Mexico it has not been possible to completely replace DC motors, due to their ease of controlling speed in a greater range than induction motors.

- **Control systems**

There are two types of controls in general; classic control and intelligent control, referring only to the first one, we begin with the definition of the regulators that make up a controller within which are the proportional integral control (PI), proportional derivative control (PD) and the proportional integral derivative control (PID). Regarding the controller to be used in this article, the PI, with which it is sought to obtain a previously selected constant speed, either under load conditions or under vacuum conditions. Regulators are devices that when comparing a reference signal with an output signal, produce an error signal, this being the difference from the previous two and thanks to this signal the input signal to the system is increased or decreased. Currently there are two types of control systems, which can be conventional control better known as classic control or intelligent control.

To control the speed of the direct current machine, a control system of the conventional type or classic control will be implemented, such as:

a) Integral Proportional Controller (PI). As mentioned above, there are different types of regulators, however, a regulator by itself cannot execute the control action, so a combination of them is required, being known as controllers with classic control. [1,2,3,11]. Integral proportional controller (PI). It is from here that it is known by the name of controller and this first acts quickly, has a gain and corrects the error, it does not experience an offset in steady state. The mathematical expression is shown in 1.

$$U(t) = Kp * e(t) + Ki\int_0^t e(t)dt \quad (1)$$

Applying the Laplace transform to 2, the following transfer function is obtained:

$$E(S) = \left[Kp + \frac{Kp}{I(S)}\right] \quad \therefore \quad \frac{U(S)}{E(S)} = Kp\left(1 + \frac{1}{STi}\right) \quad (2)$$

The integral time regulates the integral control action, while a change in Kp affects the integral part as well as the proportional part of the control action. The reciprocal of the integral time Ti is called the replacement frequency. The reset frequency is the number of times per minute that the proportional action is repeated. The replacement frequency is measured in terms of repetitions per minute [4,5,6,12]. Its block diagram is shown in fig. 1.

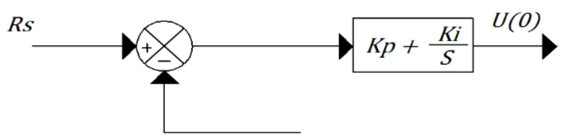


Fig. 1. Block diagram of the proportional integral control.

- **Direct Current Motors**

Direct current machines can be classified according to their utility, as a generator or as a motor, where from the constructive point of view it is the same machine, the only difference is that as a generator the counter electromotive force (emf) is greater than the terminal voltage and as motor, the generated value of emf is less than the terminal voltage, therefore the power flow is reversed, that is, the electric motor converts electrical energy into mechanical energy, that is, the reverse process to that of the generator. To carry out the implementation of the PI controller, it is carried out with a DC machine, with independent excitation and its characteristics will be mentioned below.

- DC machine, independent excitation. In order to implement the control, the machine with independent field winding (separate excitation) will be used, this type of machine is used due to the ease of speed control that it presents, since as its name says the excitation of each one-off The windings are made with totally different sources, which is why you can have three different ways of controlling their speed, which can be seen in fig. 2.

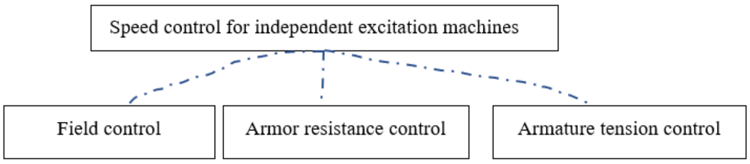


Fig. 2. Types of speed control for machines with separate excitation

Types of Control in Direct Current motors. The main reason why it was decided to use the direct current machine is because of the excellent adaptation in handling its speed, without the need to modify its construction [16]. There are three different ways to control its speed, but it should be noted that only two of them are the most important, these being: "the control of the armature voltage and the control of the field current".

- Speed control by armor resistance. With this method, control is achieved by inserting a field resistance (Rc) in the armature circuit of a series, derivative or compound motor [14]. The additional resistance in the armature circuit reduces the counter electromotive force on the motor for whatever armature current is required. Since the flux in the motor is constant and the torque depends on the armature current, the decrease in the counter electromotive force results in a speed drop in the motor. The speed of the dc machine, you can express in terms of the current of your armature, such as:

$$\omega_m = \frac{V_S - I_A R}{K_A \phi_P} \quad (3)$$

For a series or compound motor the resistance R is given by:

$$R = R_A + R_S + R_C \quad (4)$$

While for a derivative it is given by:

$$R = R_A + R_C \quad (5)$$

From equation 5, it is evident that any increase in the value of the control resistor (Rc) decreases the speed of the motor. The armature resistance control method, therefore, is appropriate to operate the motor at a lower speed than the rated speed, while maintaining the developed torque.

The disadvantages of this method of speed control are the following: considerable power loss in the field resistance Rc, decrease in motor efficiency, and poor speed regulation of the derivative and compound motor.

- Armature Tension Control. This method consists of applying a voltage lower than that specified at the armature terminals, whereas for shunt and compound type motors, the shunt field winding must keep the voltage at a constant level. This method of speed control is also known as the Ward-Leonard system. The advantage of this method is that it eliminates the excessive power loss generated by the implementation in the control of the armature resistance, in addition to having a wide range of speed variation in any direction of rotation. Another advantage of the Ward-Leonard system is that it can regenerate or return energy from machine movement to supply lines. The main disadvantage is that it requires two power sources to control the speed of a derivative or compound motor, another disadvantage is that having three machines will be less efficient than having only one.

- Field Current Control. The speed of a dc motor, can also be manipulated or it can be varied by modifying the field flux, it is obtained from a constant armature voltage thus in this way the motor speed will change in inverse proportion to the flux, and when increasing the flow speed will decrease, on the contrary if the flow decreases its speed increases, for this type of control a field rheostat is implemented in series with the field mainly in machines in shunt connection [13,14,15]. This type of control can also be called flux variation control where the flow of current can be limited by means of the field rheostat, thereby limiting the magnetic flux induced to the armature, this type of control It has some disadvantages which are the weakening of the flow, this type of control is commonly used when it is desired to bring the motor to a speed above the nominal speed, also called base speed.

II. METHODOLOGY

Next, the elements used to carry out the methodology are described, with which the integral proportional control system was implemented in a DC machine, with separate excitation. Each element that makes up the control system will be described in detail in order to broaden the understanding of the system. Fig. 3, shows the general diagram of the elements that make up the integral proportional control system and subsequently the description of each element that makes up the speed controller.

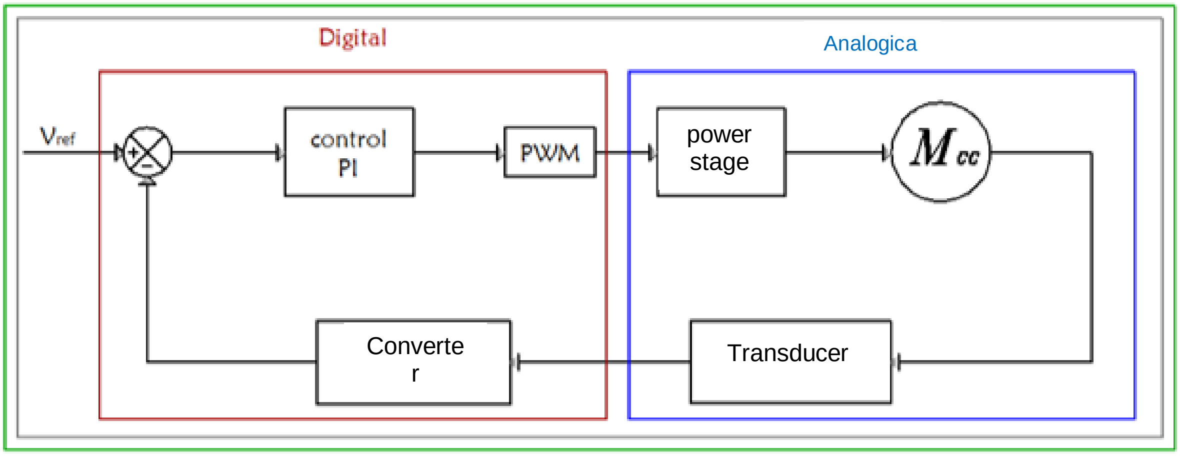


Fig. 3. General diagram of the elements that make up the PI control system

The general diagram shows the classification of signals which are digital signal and analog signal. The first type of signal can also be known as a control stage and is generally made up of the ARDUINO UNO R3 electronic board, this being a microcontroller, said microcontroller is in charge of transmitting the control signal previously programmed by means of a control algorithm. Based on an integral proportional type controller, this same electronic board also has the pulse width modulation (PWM) signal and the analog-digital converter stage. The analog signal is generally described by the power stage, such as the machine, the encoder and the power circuit, since in this section high and intermediate voltage values are handled to carry out the control stage. [8,9]

A. Digital Signal. As mentioned above, a classic proportional integral type controller was implemented which is responsible for maintaining a constant speed either under load conditions or under no-load conditions, the algorithm corresponding to this controller is programmed into the microcontroller in order to obtain a signal control through feedback, at the end of the article, the programming algorithm for this type of controller is shown in an annex.

Programming Algorithm for the PI Controller. The algorithm presented in this section is the one programmed within the microcontroller which is responsible for maintaining the motor at a constant speed, the present algorithm has a sequence of steps which is described on the right side of each of the actions that develops the microprocessor. See annex at the end of the article.

Pulse width modulation (PWM). Basically the function of this type of signal is to emit a square signal instead of a continuous signal, said square signal is formed by pulses of constant frequency approximately 490Hz for the case of the plate used, the function of this type of signal is in vary the duration of these pulses, which consequently will be varying the resulting average voltage [5,6,7]. In other words, the shorter the pulse, the greater the distance between them, so as a result there will be a lower voltage. [5,6,7]

In the case of the PWM implemented by the ARDUINO UNO R3 electronic card, it has a resolution of 8 bits, so there is a maximum of 2 ^ 8 = (256) different possible values. The analog voltage difference between any two values you want, (for example. Between 127 and 128) can be calculated by means of the maximum voltage value 5V between the number of possible combinations (256), on the card used it can be mentioned that the pins PWM are controlled by three different timers that maintain the constant frequency of the pulses emitted. Pins 3 and 11 are controlled by “Timer 1”, pins 5 and 6 are controlled by “Timer 2” and pins 9 and 10 are controlled by “Timer 3”. [7]

B. Analog Digital Converter. Analog signal. The analog signal can also be called a power stage and is made up of a power circuit, power supply (dl 2613), power supply (dl 30018), DC machine independent excitation motor used in the control system (dl 10200 a1), direct current generator (dl 10250 a1), tachometer (dl

2025dt), diode (dl 2602), main source for generator field power (dl2600att) and load connected to generator terminals (dl 3626).

C. Power Circuit. It is also known as a power amplifier or gain stage, where its main function is to electrically isolate the digital signal with respect to the analog signal in addition to increasing the level of an input signal by an output signal with greater amplitude, for the In the case of the control implemented in this work, the circuit shown in fig. 4 is used.

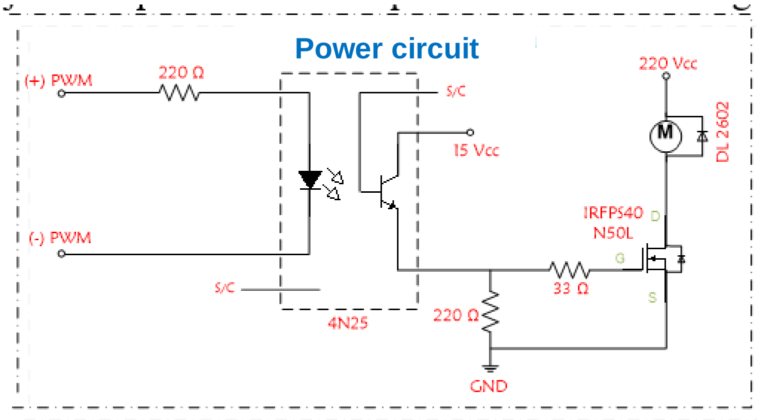


Fig. 4. Power circuit

In the circuit of fig. 4, different electronic elements are implemented such as the 4N25, this being an optocoupler, this first element is in charge of receiving the signal from the PI controller, which is represented as a pulse width modulation and amplifies it. At a higher voltage given by an external source of 15Vdc, this being the necessary or required voltage level to be able to operate the second electronic element, which is a MOSFET (IRFPS40N50L), this second element is responsible for separating the control stage with respect to to the power stage where as a control stage in this section there is a maximum voltage of approximately 15 VDC and at the end of the output there is a voltage of 257 VDC. On the other hand, a series of resistors of different values are also used as can be seen in fig. 4. The first resistance with a value of 220 Ω seen from the extreme left at the input of the PWM is implemented in order to obtain a voltage drop, and thus provide a required voltage level across the optocoupler terminals. Another resistance used of the same value is placed on pin 4 towards negative in order to ensure a logical zero, this is implemented to avoid false trips of the MOSFET, when it is out of service or out of operation. Finally, there is the connection of a resistance with a value of 33Ω which is obtained from a series of calculations.

III. APPLICATION OF THE METHODOLOGY

In this section, the start-up of the motor is carried out by means of the PI controller, the main function of the control system is to keep the dc motor in operation at 2000 revolutions per minute (rpm) in fig. 5, you can physically observe the components that make up the control system, which have already been mentioned.

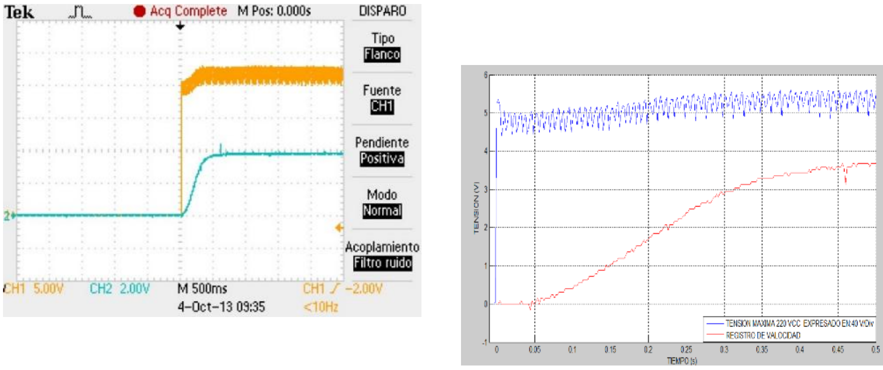
Fig. 5. Physical elements that make up the control system

- **Results obtained in the tuning of the PI controller**

To obtain the factors Kp, Ti,. The ziegler–nichols tuning method is implemented, where five different steps are performed for the implementation of the method.

- Application of the unit pulse.
- Step impulse response graphs are obtained.
- The approximation of the velocity curve is obtained.
- The inflection point of the curve is obtained.
- The tangent to the curve is obtained.
- The time factors L and T are determined.
- Formulas corresponding to the first method are applied.

We begin by doing the first test of the motor by introducing a unit ramp to nominal voltage values in which the graphs of motor operating voltage and motor speed are obtained by means of the transducer, in fig. 6(a) it is graphically observed the behavior of the engine when implementing a unit branch to it.



(a) *(b)*

Fig. 6 (a) Behavior with unit ramp. (b) behavior to unit impulse with Matlab software.

After the implementation of the unit ramp, we begin with the determination of the polynomial with which the approximation of the curve will be obtained, in fig. 7 the approximation to the curve can be graphically observed.

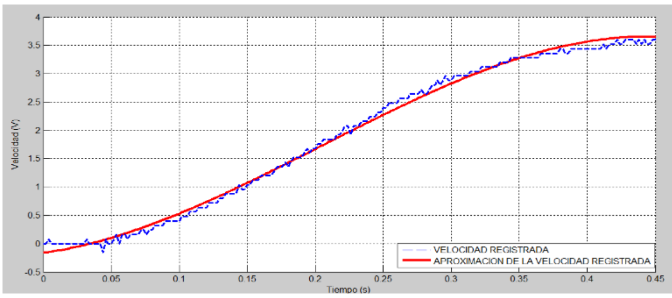


Fig. 7. Approach to the velocity curve

After this, the second derivative of the polynomial is carried out to determine the value of the inflection point to later replace this value in the original polynomial. Once we have the values of the variable's "X" and "Y". The values immediately above are taken as second values of "X" and "Y" to obtain the equation of the slope and thus be able to observe it graphically. Finally, the tangent line that passes through the inflection point is obtained and the value of Kp and Ti, using formulas given by the Ziegler - Nichols method in its first method. In fig. 8, the obtained results necessary to carry out the tuning of the PI controller are graphically observed.

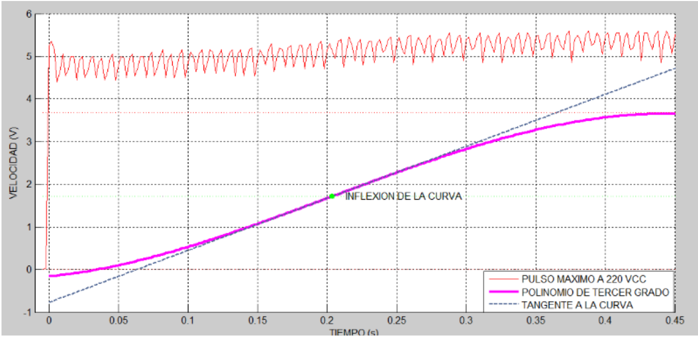
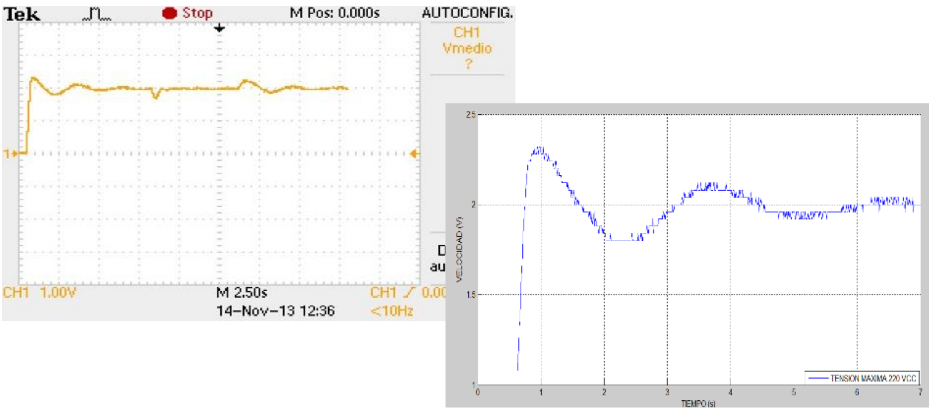


Fig. 8. Results obtained from pulse step approximation and tangent to the curve

- **Tests carried out on the control system.** One of the main tests that were carried out on the system are those referring to the control stage, this in order for the programming code to execute the necessary instructions, and once the power stage is activated, it will start with speed regulation. of this machine, in the previous tests carried out with the first constants calculated by the Ziegler-Nichols method, they were not stable, for this reason the first calculated values are considered a reference point and from these the experiments with the purpose of obtaining these factors by trial and error.

- **Starting the DC motor. in vacuum.**



(a) (b)

Fig. 9. (a) Speed behavior at idle start. (b) Oscillations present at no-load start.

- **Starting the DC motor. under load**

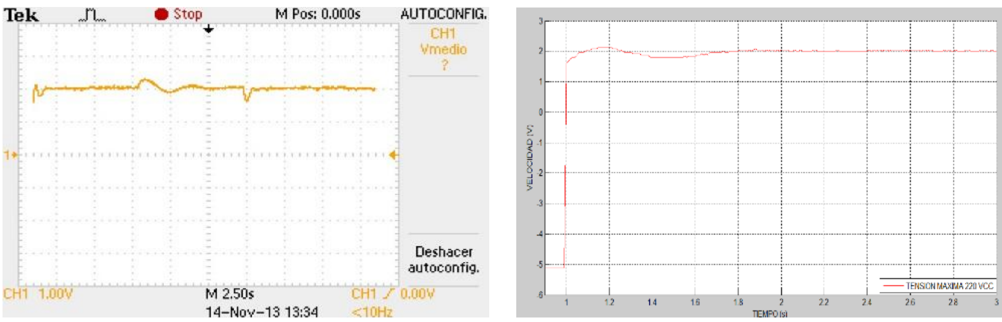


Fig. 10. (a) Starting speed behavior at full load. (b) Oscillations present at load start.

- **Engine operation in the event of load variations.**

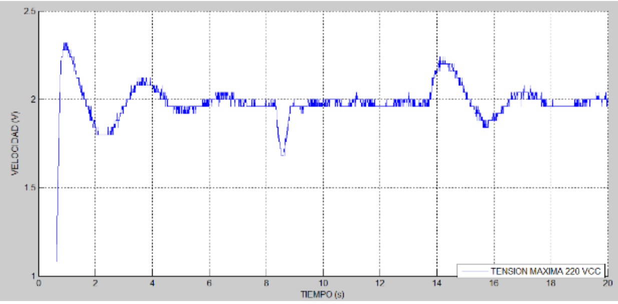


Fig.11. Behavior under load and no-load conditions

Fig. 12. Experimental behavior under load and no-load conditions

IV. CONCLUSION

When carrying out an analysis of the graphs obtained experimentally, it can be observed that the controller always seeks to reestablish the speed at a speed established as a reference, with which it is said that the controller acts appropriately. It is highly relevant to note that the behavior is different under load conditions than under vacuum conditions, which is why it has a direct effect on the recovery time.

The behavior of the PI controller can be analyzed under two different conditions (load or vacuum) where under load conditions the resetting time is shorter than under vacuum conditions, this is due to the presence of a force that opposes the mechanical movement of the motor shaft so the generated overdraft is less and it takes less time to bring it to its reference speed. Otherwise, when a start-up is carried out under vacuum conditions, since there is no force opposing the mechanical movement, a greater overdraft is generated, which affects the controller by prolonging its resetting time. This type of controller is usually widely used in generators for the reason that a generator must always generate the same amount of energy regardless of the load variations that are added or subtracted from it.

During the elaboration of the PI controller, it was required to determine the Kp and Ti factors, where these factors were approximated by the Ziengler Nichols method, but it is important to mention that the values obtained by this method are only an approximation to the values that provide the desired stability to the system, and these values are experimentally determined by trial and error. The controller used in the present work is implemented in a DC machine. with independent excitation, to which a DC generator was coupled. and in turn this feeds a resistive load, in which a simulation at the micro level could be made of what would be a generator at the macro level. To this, load variations are caused to observe the behavior and it could be observed that the controller always looks for its reference level so it can be understood that the generator will always be generating the same amount of energy regardless of the variations that are had in the load connected to generator terminals. The reason why it is decided to implement a reduced voltage start or also known as ramp start is for the reason that it avoids currents above the rated motor current that could be the cause of a fault in the control system (stage digital). It is worth mentioning that the components that make up the system are adequate and each one with the appropriate characteristics to work together, so the system could not work without any of these components.

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