

# IMPROVING EFFICIENCY IN DC MOTORS: A COMPARISON BETWEEN PID-FUZZY AND PID- GENETIC ALGORITHM

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## ABSTRACT

With the advent of Industry 4.0 and the continued progression of automation driven by Artificial Intelligence (AI), optimizing industrial processes has become a critical need. The growing preference for brushless DC motors in a variety of industrial sectors can be attributed to their significant advantages, such as high efficiency, low maintenance requirements and speed control capabilities, in contrast to conventional induction motors. Against this backdrop, this research set out to examine the effectiveness of two controller optimization methods incorporated with Proportional Integral Derivative - FUZZY and Proportional Integral Derivative - Genetic Algorithm, for the control of DC electric motors. The results showed that the Proportional Integral Derivative - FUZZY method achieved superior performance compared to the Proportional Integral Derivative - Genetic Algorithm, considering the parameters and criteria defined, and is an effective, versatile and robust method for controlling these motor systems.



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## 1. INTRODUCTION

With the evolution of Industry 4.0 and the increasing incorporation of automation using Artificial Intelligence (AI), there is a growing demand when it comes to controlling processes quickly and efficiently (Santos & Millán, 2013; Santos et al., 2014; Vieira et al., 2019; Santos et al., 2019; Teixeira et al., 2022). It is necessary to improve the organization (Talapatra et al., 2022; Castro et al., 2020), towards sustainability (Kumar et al.,

2023; Mohapatra et al., 2025; Singh et al., 2025), in order to improve the economy (Yülek & Santos, 2022).

Direct Current (DC) brushless motors are becoming increasingly popular in various industrial sectors (Karnavas et al., 2019; Malik et al., 2024; Tsai & Ko, 2017). These motors are used in household appliances, automobiles, the aerospace industry, automation and instrumentation equipment, among many other applications. This is due to their characteristics such as:

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high efficiency, low maintenance, torque speed characteristics and speed control, when compared to induction motors (Karnavas et al., 2019; Kovkin et al., 2016; Umland et al., 2023).

Therefore, to control a process, it is essential to use a controller to guarantee the energy efficiency of the motors (Ali et al., 2022; Banaszek, 2024; Feng et al., 2025). Process control using negative feedback is the most common form of automatic control. The most common automatic controller is the Proportional-Integral-Derivative (PID) due to its simplicity, robustness and applicability (Alam Shithil et al., 2025; Feng et al., 2025; Raj, 2025).

Due to the high demands placed on the PID controller, different tuning methods are used (Audomsi et al., 2025; Ersali et al., 2025; Sain et al., 2025). This paper compares two types of advanced control for DC motors based on PID-FUZZY and PID-GA, analyzes the results and discusses the conclusions drawn. Among the results obtained in this research, considering the criteria adopted, it was possible to verify that PID-FUZZY, used as a control method for DC motor systems, outperformed the PID-GA control method.

## **2. THEORETICAL FRAMEWORK**

The construction of a DC motor is considerably more complicated than that of an AC motor, mainly because of the commutator, brushes and armature windings. The maintenance of the brush set found in DC motors is higher when compared to AC motor designs, since an AC induction motor does not need a commutator and brushes. As a result, DC motors tend to require more frequent inspection and replacement of mechanical components, which can increase operational and maintenance costs over time. Important parameters used to predict DC motor performance are speed, torque and power, as these variables describe the relationship between electrical input and mechanical output and help determine the motor's efficiency and suitability for specific applications (Arokianathan et al., 2024; Biswas et al., 2024; Kroics et al., 2024).

The information provided by the author on speed, torque and power as fundamental parameters for predicting and understanding the performance of a DC motor is indeed consistent since these parameters offer crucial insights into how the motor will work in different conditions and applications. These variables allow the evaluation of the motor's operational efficiency, load behavior, and mechanical response under varying electrical inputs. Furthermore, understanding the relationship between these parameters contributes to a more accurate analysis of system performance and reliability in practical implementations. Throughout this document, these elements will serve as the basis for structuring the research proposal and for guiding the analytical approach

adopted in the study (Kalsi et al., 2024; Kumar & Singh, 2024; Wang et al., 2024).

The combination of the parameters speed, torque and power is essential for assessing the performance of a DC motor, as these variables collectively describe the relationship between electrical energy input and mechanical energy output. A proper understanding of how these parameters interact allows engineers to evaluate the operational efficiency and mechanical capability of the motor under different load conditions. In addition, these parameters support the analysis of performance limitations and help identify the most appropriate operational range for the equipment. Therefore, selecting the right configuration for a DC motor depends on the specific requirements of the application, including load characteristics, desired speed control, and energy efficiency considerations (Aljarhizi et al., 2023; Cheng et al., 2023; Ham et al., 2024). The fundamental equation that describes the operation of a direct current motor is Faraday's Law of Electromagnetic Induction, and in this same concept, mathematical modelling has the application of Kirchhoff's mesh law as a starting point for its application (Lee et al., 2016; Moroz, 2002; Sain et al., 2025).

## **3. RESEARCH METHOD**

The research is characterized as exploratory and also descriptive due to the fact that it deals with a problem based on bibliographic research, as well as the interpretation of the variables that impact the process through the collection of data resulting from simulations and the understanding of the relationship that the observed variables have in a process when it is approximated to a real system (Barbosa et al., 2023; Espuny et al., 2023; Azevedo et al., 2019; Reis et al., 2020; Rodrigues et al., 2020; Silva et al., 2020; Murmura et al., 2021). In line with the same author mentioned above, the data collection method used in this research was documental because the analyses and interpretations in this work came from a wide range of materials on DC motors. These materials were used to obtain the process variables by means of simulations, where through qualitative and quantitative means the cause and effect that these parameters have on the system is clarified. Therefore, in terms of its nature, this research is mixed.

As previously stated, this work involves a series of comparisons that result in the selection of one of two methods, based on the best performance, considering the selected criteria, that best adapts to the advanced control of DC motors. The selection method was divided into three stages, and each stage respectively was an experiment that tested attributes in the adaptive control of DC motors by comparing methodologies from two main categories, PID-GA and PID-FUZZY, to choose a controller that has the following premises: Effective control, versatility and robustness (Audomsi et al., 2025; Ersali et al., 2025).

### 4.1 Experiment I

The main objective of this stage was to find an optimization method considering the performance criteria outlined in section 2.6 in the search for effective control. In this stage, the selection of optimization methods incorporated with PID compared the variations of each method, where in one branch there are three

variations with GA characteristics, and another branch also has three variations, but with FUZZY characteristics. At the end of this stage, through a quantitative and qualitative analysis of the data, a comparative analysis was carried out in search of the most effective method according to the selected criteria, between the two main PID-GA and PID-FUZZY models (Figure 1).

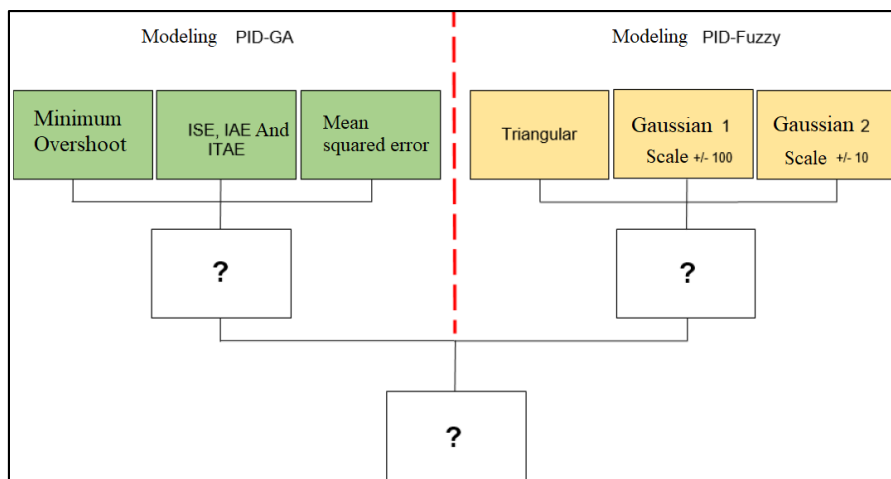


Figure 1. The initial key to the models

### 4.2 Experiment II

Versatility is the central objective of this stage. This experiment used the representatives of the adaptive control methods, PID-FUZZY and PID-GA, based on the criteria used, and compared them again in a second DC motor process plant. The idea was to choose the model capable of dealing with several DC motor loops, following the same performance criteria as the first experiment. In this context, the controllers were evaluated in terms of stability, response time, and robustness under different operating conditions of the motor. This comparative analysis makes it possible to verify the adaptability of each control strategy when applied to different system dynamics. The method between PID-GA and PID-FUZZY which shows the best DC motor control performance goes on to the last and final stage.

### 4.3 Experiment III

In this last stage, the method that had shown the best results in the previous experiments was subjected to a disturbance to approximate a real system. The robustness of the adaptive control method was tested in this experiment by changing the process variables and evaluating the controller's performance against disturbances, which are common in DC motors. Data collection was conceived in this document as follows: simulations were carried out in which, in each experiment, a DC motor plant to be controlled was initially defined, and data on the constructive parameters of the motor that makes up a plant were obtained from

academic materials. The motor data is then the input for each simulation, which generates the variables to be controlled in the process.

## 4. RESULTS AND DISCUSSIONS

As already explained in the previous topic, three experiments were carried out with different objectives, the first of which was carried out on six different controller formats incorporated with PID, divided into three versions of PID-FUZZY and three versions of PID-GA, and through simulations and data analysis the method that was most effective was selected, considering the defined criteria of DC motors. The second experiment looked at the most effective method in each category based on its performance in experiment I, where a new comparison was made using another DC motor plant, to select a versatile methodology.

In a final experiment, the method that stood out based on the results of experiment II was tested in a plant with a disturbance in the system, with the aim of proving its robust adaptive control in systems that are close to the reality of DC motors. The disturbance was intentionally introduced to evaluate the controller's ability to maintain stability and acceptable performance under non-ideal operating conditions. Both experiments are simulations of the time response behavior of DC motor controllers whose model solution was given by programming code made in MatLab language and data analysis performed almost entirely in Minitab. This computational approach allowed the systematic evaluation of controller performance and facilitated the comparison of response characteristics under different simulated scenarios.

### 4.1 Results of the experiment I

Initially, the control plant that could serve as the basis for the simulations was defined, from where the performance of each method would be measured. The data was extracted and analyzed using 25 samples or trials of each method to control a DC motor plant. The graph in Figure 2 below shows the time response of a DC motor process.

As already explained in this paper, this type of motor was chosen because it can be modeled by a second-order transfer function, where it is controlled by the armature using a constant field current. Motor data: Moment of inertia of motor and load ( $J$ ): 0.000052; Coefficient of friction of motor and load ( $b$ ):0.01; Armature resistance ( $R_a$ ):2; Armature inductance ( $L_a$ ):0.23; Electrical constant ( $K_m$ ):0.235; and Torque constant ( $K_b$ ):0.235.

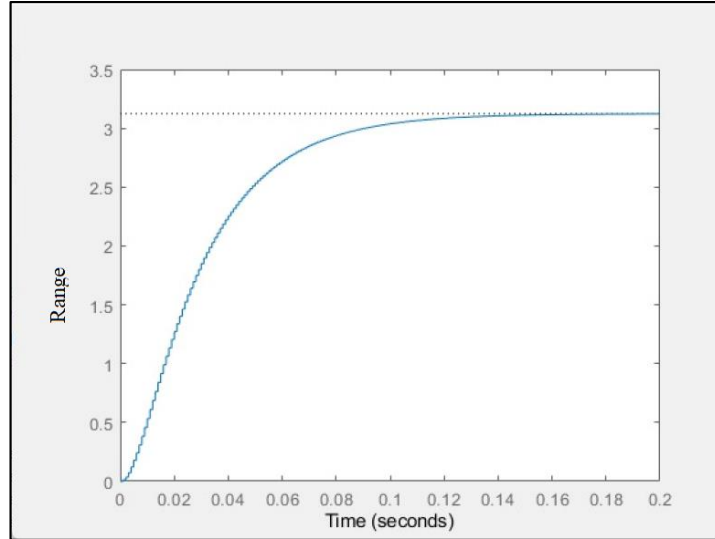


Figure 2. Initial system response

In order to make it easier to interpret the data, a code name was used for each control method format, as follows.

1. Genetic algorithms (GA): PID-GA1: Minimum Overshoot format; PID-GA2: ISA, IAE and ITAE format; and PID-GA3: Mean Squared Error format.
2. FUZZY: PID-FUZZY1: Gaussian 1 format; PID-FUZZY2: Triangular format; and PID-FUZZY3: Gaussian 2 format.

Based on the acceptance criteria (Settling Time, Rise Time and Overshoot), it can be seen that the results

obtained in the FUZZY Gaussian 1 modeling proved to be more effective when the parameters mentioned were taken into account, compared to the ISE, IAE and ITAE modeling, given that the Settling Time is much lower and that in process control applications it is a parameter that determines how quickly a system stabilizes, and therefore makes it more attractive for controlling the DC motor, and the objectives of this research.

Figure 3 below closes the analysis of the distributed branches in PID-GA and PID-FUZZY, with the chosen modeling.

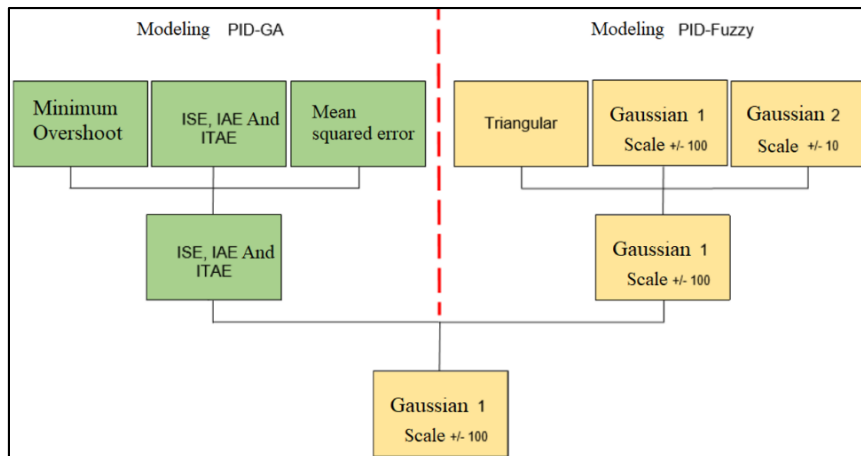


Figure 3. Selected model

## 4.2 Results of the experiment II

After the first experiment I defined a control plant, also a DC motor, which was more difficult to control its response to serve as the basis for a new round of simulations, the aim of which was to measure the performance of the methods selected in the previous PID-GA and PID-FUZZY experiment. The extraction and analysis were again carried out using 25 samples or attempts by each method to control the DC motor plant. The graph in Figure 4 below shows the time response of the new DC motor plant.

As previously stated, and based on this work, the DC motor can be modeled by a second-order transfer function, where it is controlled by the armature using a constant field current. Motor data: Moment of inertia of the motor and load ( $J$ ): 0.1; Coefficient of friction of motor and load ( $b$ ): 0.008; Armature resistance ( $R_a$ ): 0.5; Armature inductance ( $L_a$ ): 0.02; Electrical constant ( $K_m$ ): 1.25; Torque constant ( $K_b$ ): 1.25.

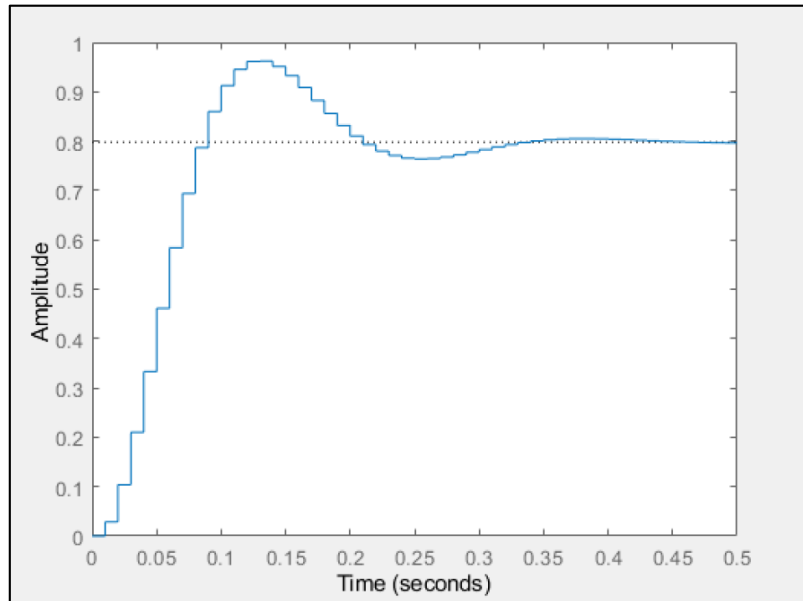


Figure 4. Initial response of the second plant system

The Figure 5 illustrates the behavior of the samples in the control process of plant 2, from which it is possible to observe the disadvantage of the GA method, when some

sample disperses from the average concentration of the data.

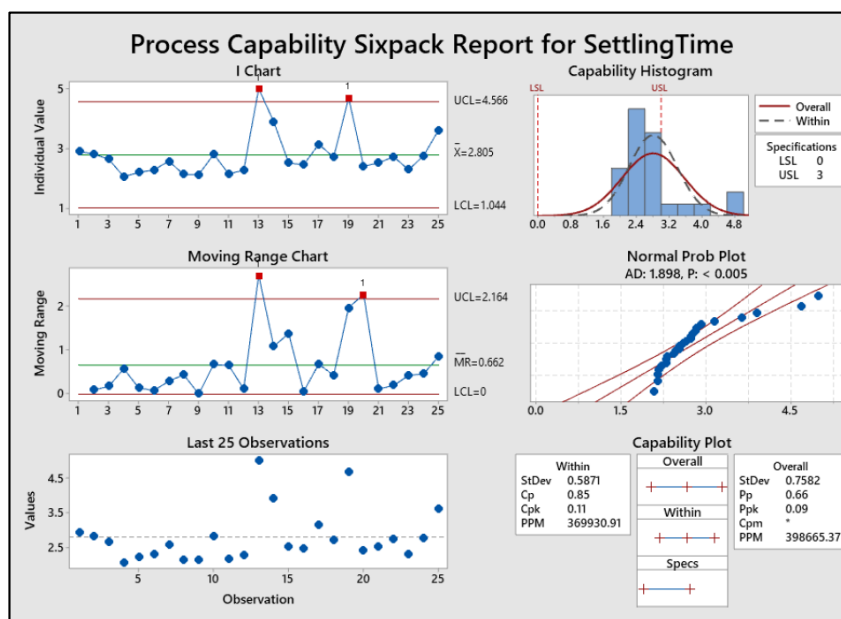


Figure 5. Initial response of the second plant system

In summary, when the Settling Time values for the two models are submitted to simulations in a second plant, the FUZZY model still shows a 71% better response time when compared to the GA model.

### 4.3 Results of the experiment III

In this last stage, a test was carried out to prove the system's robustness, in which case the plant in experiment II was subjected to disturbances. This procedure aimed to evaluate how the control strategy

behaves when the system operates under non-ideal conditions, which are commonly observed in real DC motor applications. Figure 6 below shows the results obtained for the FUZZY modeling and further structures the analysis by bringing assertive conclusions about the capacity of the chosen modeling, illustrating that it can make a total or asymptotic rejection of the disturbance. These results demonstrate the controller's ability to maintain stability and quickly recover the desired operating conditions even in the presence of external perturbations.

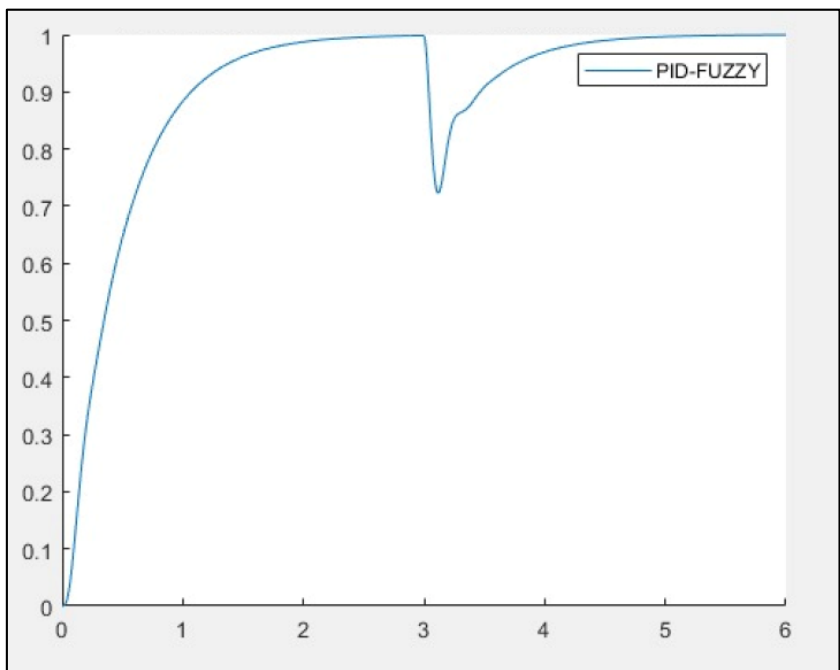


Figure 6. System response with disturbance

The disturbance was generated in Simulink using a block diagram, where an aggressive variation in the load of 30% of its reference value was simulated, proving by analyzing Figure 6 its power in adaptive control in dynamic load systems, thus being an excellent application for DC motors. The results obtained and successfully analyzed after the three experiments served as evidence to select the PID-FUZZY for the control of DC motors whose purpose may be speed or position control, depending on the application.

## 5. CONCLUSION

This work analyzed the concepts of PID-FUZZY and PID-GA and their effectiveness when compared to each other through simulations. PID controllers optimized using genetic algorithms (PID-GA) and PID-FUZZY controllers in a speed control system for a direct current (DC) motor were used to consolidate the performance of these two control approaches through simulations carried out in the MATLAB environment, from which data was extracted to serve as the basis for a comparative analysis of the controllers, using performance criteria that

influence the DC motor process. The results obtained and analyzed using Minitab software show that both optimization methods offer significant improvements over, for example, conventional PID. However, it can be seen that PID-FUZZY excels in scenarios with abrupt load changes and disturbances, while PID-GA tends to be unstable in some situations. In the context of Industry 4.0, the automation and control of DC motors plays an important role, especially with the advent of electric vehicles and highly automated production systems. In this scenario, the application of artificial intelligence techniques, such as Genetic Algorithms and FUZZY logic, is extremely important. These techniques allow controllers to adapt dynamically to changing conditions, improving the energy efficiency, stability and reliability of systems.

The PID-GA controller, which uses genetic algorithms for optimization, proved to be effective in finding the optimum settings for the PID parameters. It was able to achieve rapid convergence to the desired settings in the simulations, which minimized stabilization time and reduced overshoot, resulting in a precise and effective control alternative. The PID-FUZZY controller, on the

other hand, demonstrated a remarkable ability to deal with complex and variable systems. It excelled in situations where the DC motor's behavior was highly non-linear or subject to significant disturbances. The FUZZY logic allowed flexible adaptation of the PID controller, which resulted in effective, versatile and robust performance. This study not only contributed to the understanding of controller optimization techniques, but also provided a solid basis for future research in the area of dynamic systems control. As technology evolves and demands for high-precision control grow, the combination of PID-GA and PID-FUZZY can be considered promising solutions for a wide range of industrial applications. PID-FUZZY proved to be more effective than PID-GA when implemented in a real control project, such as DC motor speed, due to its ability

to deal more adaptively and effectively with the complexities and non-linearities inherent in the system. For future work, the suggestion is to practically implement the selected controller in a real industrial environment. There are several practical applications that can be implemented for the control of DC motors using the PID-FUZZY methodology.

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