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College Of Engineering

SCHOOL OF ELECTRONIC ENGINEERING

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SPEED CONTROL OF DC MOTOR USING FUZZY LOGIC & PI CONTROLLER

التحكم فى سرعة محرك التيار المستمر بإستخدام المتحكم المنطقى الغامض والمتحكم التقليدى

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بِسْمِ اللهِ الرَّحْمَـــنِ الرَّحِيـــمِ

الآيــــــة

قَال تَعالـــــــــــى :

(إِقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ (١) خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ (٢) اقْرَأْ وَرَبُّكَ

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سورة العلق الايه(١ - ٥)

صدق الله العظيم

Dedication

All praise to Allah, today we fold the days' tiredness and the errand summing up between the cover of this humble work.

TO the utmost knowledge lighthouse,
To our greatest and most honored prophet Mohamed - May peace and grace from Allah be upon him.

TO the spring that never stops giving, to my mother who weaves my happiness with strings from her merciful heart… to my mother and grandmother.

TO whom he strives to bless comfort and welfare and never stints what he owns to push me in the success way who taught me to promote life stairs wisely and patiently, to my dearest father.

Acknowledgement

TO whose love flows in my veins, and my heart always remembers them, to my brothers and my sisters.

TO those who taught us letters of gold and words of jewel of the utmost and sweetest sentences in the whole knowledge.
Who reworded to us their knowledge simply and from their thoughts made a lighthouse guides us through the knowledge and success path, to our honored teachers and professors. Specialist my supervisor Teacher:
Musab Mohamed Saleh AL.Hassan & MR: Modhafer Ahmed Mohammed Ahmed

Abstract

This project tries to explore the potential of using fuzzy logic methodology in controllers and its advantages over conventional PID controller, which it being the most widely used controller in industrial applications, needs efficient methods to enhance DC motor parameters. This thesis asserts that the conventional approach of PID tuning is not very efficient due to the presence of non-linearity in the system where the output of the conventional. PID system has a quite high overshoot and settling time.

The main focus of this project is to apply fuzzy logic techniques to get an output with better dynamic and static performance.

The project also discusses the benefits and the short-comings of both the methods. The results obtained from simulation using MATLAB Simulink for fuzzy logic and PID control show that overshoot reduced (88.89%) and settling time reduction was (75.89%) and peak time was (3.22%). On the other hand the rise time became higher than in PID (44.40%).

المستخلص

يحاول هذا المشروع إستكشاف إمكانية استخدام منهجية متحكم المنطق الغامض ومايميزه عن المتحكم التقليدي الذى هو الاكثر استخداما على نطاق واسع فى التطبيقات الصناعيه . إلا انه يحتاج الى أنظمه اضافيه لتحسين معاملات التحكم فى محرك التيار المستمر.حيث ان هذه المعاملات فى المتحكم التقليدى ذات قيم عاليه غير مرغوب فيها وذات سلوك لاخطى.

التركيز الرئيسي في هذا المشروع هو تطبيق متحكم المنطق الغامض للحصول على تحسين فى معاملات الاداء.

كما يناقش المشروع المقارنه بين متحكم المنطق الغامض والمتحكم التقليدى ، فوجدنا النتائج المتحصل عليها من المحاكاه بإستخدام الماتلاب لمتحكم المنطق الغامض واضحه وظهرت فى إنخفاض نسبة تخطى الاستجابه للحاله المستقره بنسبة ٨٩.٨٨% ، وإنخفاض فى زمن استقرار النظام بنسبة ٧٥,٨٩% وإنخفاض ايضا فى الزمن المطلوب للوصول الى اعلى قمه بنسبة ٣,٢٢% مع ذياده فى الزمن المطلوب لوصول الاستجابه الى٠,٩ من القيمه النهائيه بنسبة ٤٤,٤٠%.

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List of Symbols

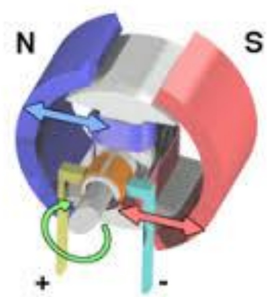
Symbols	Meaning
J	moment of inertia of the rotor
B	motor viscous friction constant
K_b	Electromotive force constant
K_t	Motor torque constant
R_a	Electric resistance
L_a	Motor Inductance
L_f	Friction Torque
T	Time constant
U_a	the reference voltage
W_R	the rotational speed of the shaft

List of Abbreviations

Abbreviations	Meaning
DC	Direct Current
EMF	Electrical Mutual Force
PID	Proportional Integral Derivative
FLC	Fuzzy Logic Controller

CHAPTER ONE

INTRODUCTION



Chapter one

Introduction

1.1 Background

For the past years DC motors are widely used in industries. There mainly preferred due to the fact that they offer good speed controllability. Most of the applications require precise speed control and accurate dynamic performance. A normal DC motor available in the market cannot satisfy the requirement of the industry due to the problem of torque controllability.

Hence in order to improve the dynamic response of the DC motors controllers are introduced. In this project the actual timer response of the DC motor is experimentally determined using the transfer function and the time response analysis is done by the introduction of different types of controllers. From the analysis an efficient controller is proposed. [1]

The development of high performance motor drives is very important in industrial as well as other purpose applications such as steel rolling mills, electric trains and robotics .Generally a high performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task .DC drivers ,because of their simplicity ,ease of application ,high reliabilities, flexibilities and favorable cost have long been a backbone of industrial application, robot manipulators and home appliances.

A DC motor provides excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horsepower rating. DC motor have a long tradition of use as adjustable speed machines and wide range of options have evolved for this purpose .

in these applications, the motor should be precisely controlled to give the desired performance. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types, the controller can be: Proportional Integral (PI). Proportional Integral Derivative (PID), Fuzzy Logic Controller (F L C).

Proportional- Integral – derivative, controller operates the majority of the control system in the world .It has been reported 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity ,clear functionality, applicability and ease of use offered by PID controller .

PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly. [8]

The other type of controller to be use is a fuzzy logic controller for speed control of a DC motor; Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required.

1.2 Problem statement

In recent years DC motors are widely used in robotics because of their small size and high energy output. They are excellent for powering the drive wheels of a mobile robot as well as powering other mechanical assemblies.

It is often demanded in the industries that the drive should have efficient speed control in lesser time and steady state performance as quick as possible. In order to improve the time response of the DC motor controllers has been introduced in this project. A detailed analysis of the controllers illustrates the effectiveness of the improvement in both transient state and steady state behavior of the DC motor.

1.3 proposed solution

Using PID controller and Fuzzy logic controller to improve both transient state and steady state behavior of the DC motor.

1.4 Objectives:

The aim of this project is to design a fuzzy logic controller for speed control of a DC motor.

- To Design speed control system of DC motor using conventional controller.
- To Design speed control system of DC motor using fuzzy logic controller.
- To Compare between PID controller and Fuzzy logic controller and evaluate Performance

1.5 Methodology

The speed control of a separately excited DC motor is performed using PI and fuzzy logic controller in MATLAB environment. The output response of the system is obtained by using two types of controllers, namely, PI and fuzzy logic controller. The performance of the designed fuzzy controller and classic PI Speed controller is compared and investigated, comparing effectiveness and efficiency of Fuzzy logic control than conventional PI controller.

Conventional PI controller: The transfer function of the DC motor is used in the modeling of the PI controller. The overall system model is represented in form of a block diagram The MATLAB Simulink software is used in the analysis of the controller by studying the response generated from the modeling and simulation of the controller.

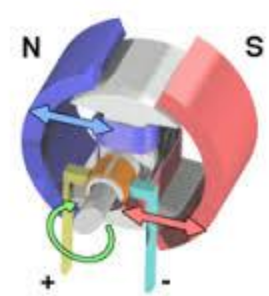
The controller is designed based on the expert knowledge of the system, which is used to tune the fuzzy logic controller. The tuning approach employs the use of MATLAB M-files and functions to manipulate the fuzzy inference system and scaling gains, run the Simulink based simulation, check the resulting performance and continuously modify the fuzzy inference system for a number of times in search for an optimal solution. MATLAB M-files where utilized for the encoding, testing and decoding of each of the tuned FLC parameters. This includes the fuzzy logic rule base, the membership function definition of the linguistic variables and the scaling gains of the controller.

1.6 Research Outline

A project contain five chapters, Chapter one is the introductory chapter ، Chapter tow discusses related work done to address the concept of DC motor and types of its controller technique, Chapter three describes the mathematical modeling of DC motor and PID modeling in addition To fuzzy logic role. Chapter four summarizes the test results، finally the conclusion and recommendations for future work are given in Chapter five.

CHAPTER TWO

LITERATURE REVIEW



2.1 BACKGROUND

This chapter focused in literature review for each component in this project. All the component is describe in details based on the finding during the completion of this project.

2.2 INTRODUCTION

2.2.1 DC Motor

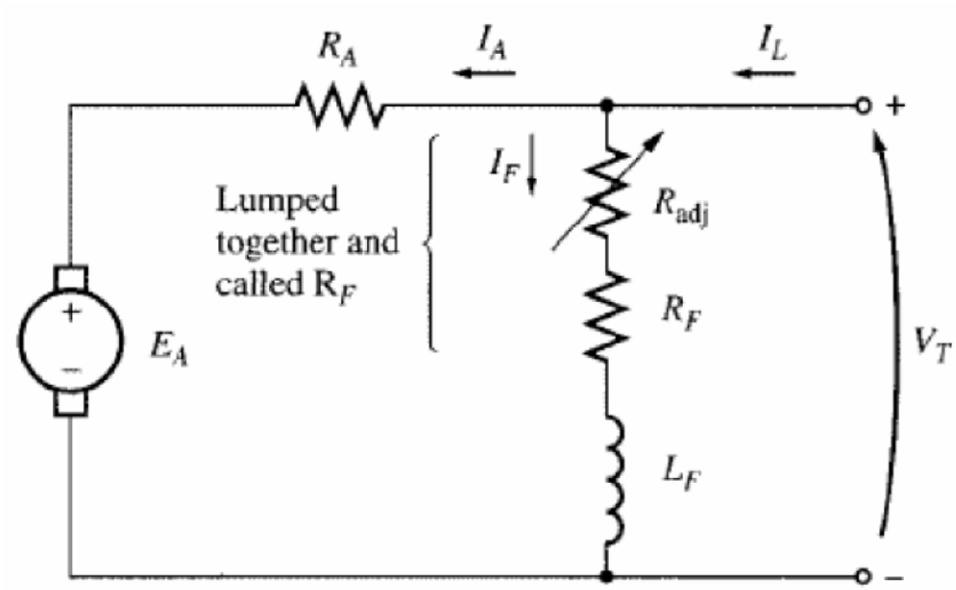
Accurate control is critical to every process that leads to various types of controllers which are being widely used in process industries. Tuning methods for these controllers are very important for process industries. Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required.

2.2.2 Types of DC Motor

Like generators, there are three types of DC motors characterized by the connections of field winding in relation to the armature viz.

1. Shunt-wound motor:

   Shunt-wound motor in which the field winding is connected in parallel with the armature. The current through the shunt field winding is not the same as the armature current. Shunt field winding are design to produce the necessary m.m.f by means the relatively large number of turns of wire having high resistance. Therefore, shunt field current is relatively small compared with the armature current.



Fid 2.1: Equivalent Circuit of Shunt-Excited DC machine

2. Series-wound motor

Series-wound motor in which the field winding is connected in series with the armature. Therefore series field winding carries the armature current. Since the armature passing through a series field winding is the same as armature current, series field windings must be designed with much fewer turns than shunt field weddings for the same m.m.f therefore, a series field winding has a relatively small number of turns of thick wire and, therefore, will possess a low resistance.

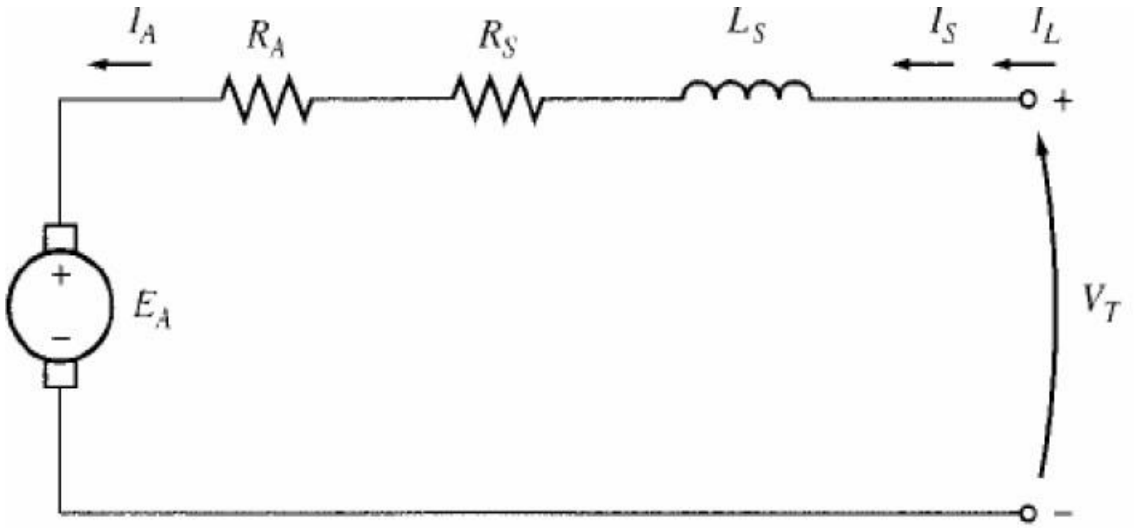


Fig 2.2: Equivalent Circuit of Series Motor

3. Compound-wound motor

Compound-wound motor, which has two field windings; one connected in parallel with the two types of compound motor connection (like generators). When the shunt field winding is directly connected a cross the armature terminals, it is called short shunt connection. When the shunt winding is so connected that it shunt the series connection of armature and serial field, it is called long shunt connection. The compound machines (motors) are always designed so that flux produced by shunt field winding is considerably larger than the flux produce by the series field winding therefore, shunt field in compound machine is the basic dominant factor in the production of the magnetic field in the machine.

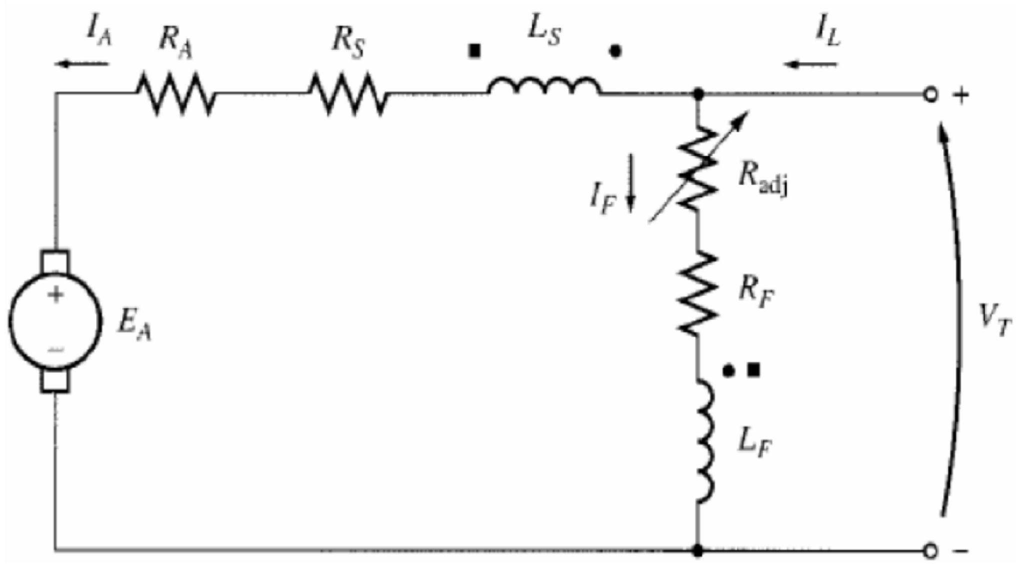


Fig 2.3: Equivalent Circuit of Compound Excited DC Motor

2.2.3 Controller Design

Conventional control has provided numerous methods for constructing controllers for dynamic systems. Some of these are listed below:

- Proportional-integral-derivative (PID) control: Over 90% of the controllers in operation today are PID controllers (or at least some form of PID controller like a P or PI controller). This approach is often viewed as simple, reliable, and easy to understand. Often, like fuzzy controllers, heuristics are used to tune PID controllers (e.g., the Zeigler-Nichols tuning rules).

- Classical control: Lead-lag compensation, Bode and Nyquist methods, rootlocus design, and so on.

- State-space methods: State feedback, observers, and so on.

- Optimal control: Linear quadratic regulator, use of Pontryagin's minimum principle or dynamic programming, and so on.

- Nonlinear methods: Feedback linearization, Lyapunov redesign, sliding mode control, back stepping, and so on.

- Adaptive control: Model reference adaptive control, self-tuning regulators, nonlinear adaptive control, and so on.

Basically, these conventional approaches to control system design offer a variety of ways to utilize information from mathematical models on how to do good control.

Sometimes they do not take into account certain heuristic information early in the design process, but use heuristics when the controller is implemented to tune it (tuning is invariably needed since the model used for the controller development is not perfectly accurate). Unfortunately, when using some approaches to conventional control, some engineers become somewhat removed from the control problem (e.g. when they do not fully understand the plant and just take the mathematical model as given), and sometimes this leads to the development of unrealistic control laws.

Sometimes in conventional control, useful heuristics are ignored because they do not fit into the proper mathematical framework, and this can cause problems. PID controllers use a 3 basic behavior types or modes: P - proportional, I - integrative and D - derivative. While proportional and integrative modes are also used as single control modes, a derivative mode is rarely used on it’s own in control systems. Combinations such as PI and PD control are very often in practical systems.

2.2.3 PID CONTROLLER

1. **P Controller**:

In general it can be said that P controller cannot stabilize higher order processes. For the 1st order processes, meaning the processes with one energy storage, a large increase in gain can be tolerated. Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics. A large controller gain will result in control system with: a) smaller steady state error, i.e. better reference following b) faster dynamics, i.e.

broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise c) smaller amplitude and phase margin When P controller is used, large gain is needed to improve steady state error.

Stable systems do not have problems when large gain is used. Such systems are systems with one energy storage (1st order capacitive systems). If constant steady state error can be accepted with such processes, than P controller can be used.

Small steady state errors can be accepted if sensor will give measured value with error or if importance of measured value is not too great anyway.

2. PI Controller

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future.

This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

3. PD Controller:

D mode is used when prediction of the error can improve control or when it necessary to stabilize the system. From the frequency characteristic of D element it can be seen that it has phase lead of 90°. [2] Often derivative is not taken from the error signal but from the system output variable. This is done to avoid effects of the sudden change of the reference input that will cause sudden change in the value of error signal. Sudden change in error signal will cause sudden change in control output. To avoid that it is suitable to design D mode to be proportional to the change of the output variable.

PD controller is often used in control of moving objects such are flying and underwater vehicles, ships, rockets etc. One of the reason is in stabilizing effect of PD controller on sudden changes in heading variable y (t). Often a "rate gyro" for velocity measurement is used as sensor of heading change of moving object. [2]

4. PID Controller:

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set-point. The controller attempts to minimize the error in outputs by adjusting the process control inputs.

PID controllers use a 3 basic behavior types or modes and is accordingly sometimes called three term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element.

The mathematical equation governing PID control is given by:

$$PID_{out} = K_p r(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt}$$

(2.1)

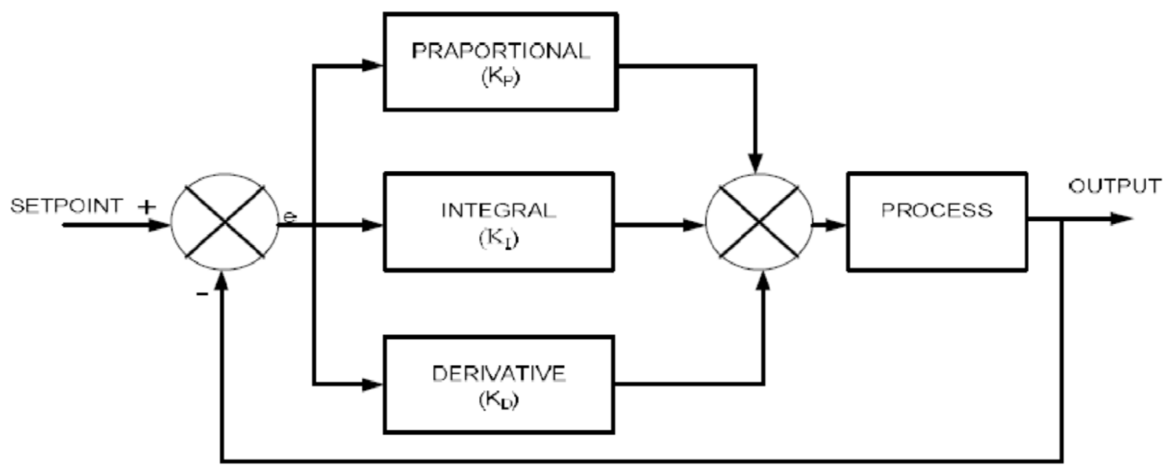


Figure 2.4: PID controller

PID controller:

While proportional and integrative modes are also used as single control modes, a derivative mode is rarely used on its own in control systems. Combinations such as PI and PD control are very often in practical systems.

PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant Ti, which increases speed of the controller response.

PID controller is used when dealing with higher order capacitive processes (processes with more than one energy storage) when their dynamic is not similar to the dynamics of an integrator (like in many thermal processes). PID controller is often used in industry, but also in the control of mobile objects (course and trajectory following included) when stability and precise reference following are required. Conventional autopilot is for the most part PID type controllers.

Table 2.1: effects of Coefficients

Parameter	Speed of response	Stability	Accuracy
Increasing K	increases	deteriorate	improves
Increasing Ki	decreases	deteriorate	improves
Increasing Kd	increases	improves	no impact

2.2.5 PID Tuning Methods

Tuning is adjustment of control parameters to the optimum values for the desired control response. Stability is a basic requirement. However, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another.

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, some of them:

- Manual tuning method.
- Good Gain method.

- Ziegler–Nichols tuning method.
- PID tuning software methods.

1. **Manual Tuning Method**:

In manual tuning method, parameters are adjusted by watching system responses. K_p , K_i, K_d are changed until desired or required system response is obtained. Although this method is simple, it should be used by experienced personal.

One Manual Tuning Method Example:

Firstly, K_i and K_d are set to zero. Then, the K_p is increased until the output of the loop oscillates, after obtaining optimum K_p value, it should be set to approximately half of that value for a "quarter amplitude decay" type response. Then K_i is increased until any offset is corrected in sufficient time for the process. However, too much K_i will cause instability. Finally, K_d is increased, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much K_d also will cause excessive response and overshoot.

A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a K_p setting significantly less than half that of the K_p setting causing oscillation.

Table 2.2: Effects of changing control parameters.

Parameter	Rise Time	Over shoot	Settling Time	S.S Error	Stability
Kp	Decrease	Increase	Small Change	Decrease	Worse
Ki	Decrease	Increase	Increase	Significant Decrease	Worse
Kd	Minor Dec	Minor Dec	Minor Dec.	No change	If Kd small Better

2. Good Gain method

The Good Gain method is a simple method which seems to give good results on the lab and on simulators. The method is based on experiments on a real or simulated control system, (A benefit of the method as compared to the Ziegler-Nichols' closed loop method, is that it does not require the control system to be brought into sustained oscillations in the tuning phase.) The procedure assumes a PI controller, which is the most commonly used controller function (more common than the P controller and the PID controller).

4. Ziegler–Nichols tuning method

This method was introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s. They described two methods for tuning the parameters of P-, PI- and PID controllers. These two methods are the Ziegler-Nichols' closed loop method, and the Ziegler-Nichols' open loop method.

Ziegler and Nichols used definition of acceptable stability as a basis for their controller tuning rules: The ratio of the amplitudes of subsequent peaks in the same direction (due to a step change of the disturbance or a step change of the set point in the control loop) is Approximately ¼.

$$\frac{A2}{A1} = \frac{1}{4}$$

However, there is no guaranty that the actual amplitude ratio of a given control system becomes 1/4 after tuning with one of the Ziegler and Nichols' methods, but it should not be very different from 1/4.

This definition of acceptable stability implies worse stability than the definition given above.

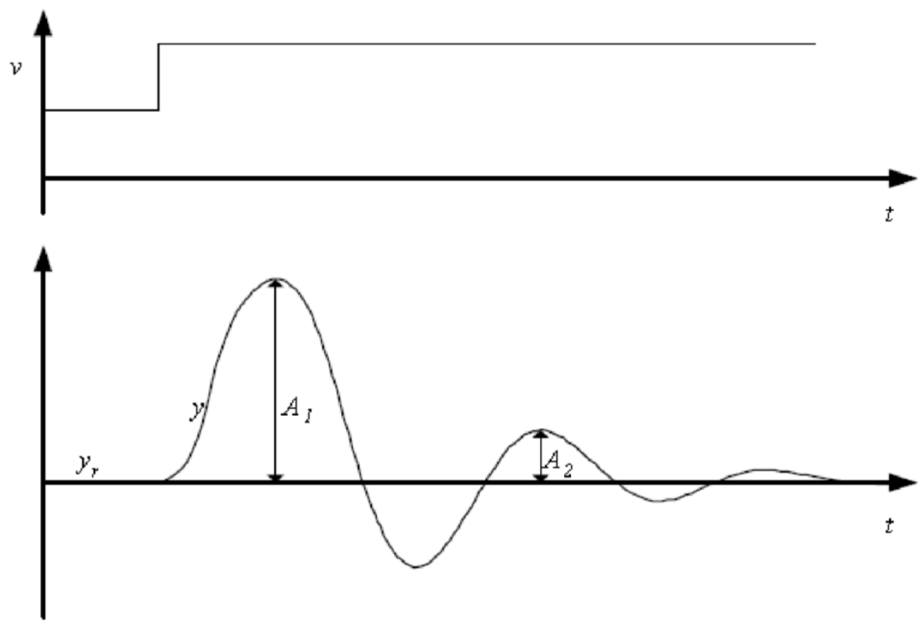


Fig2.5: If A2/A1 ≈ 1/4 the stability of the system is ok, according to

Ziegler and Nichols.

It has actually become common point of view that the 1/4 decay ratio of the step response corresponds too poor stability of the control loop. If you think that the stability of the control loop becomes too poor, you can try to adjust the controller parameters. The first aid, which may be the only adjustment needed, is to decrease K_p [1, 3, 4, 5, 6, 7, 8].

It is also important to remember the impact of the measurement noise on the control signal. The more aggressive controller — fast control — the more sensitive is the control signal to the measurement noise. Again, to decrease this sensitivity, the controller gain can be decreased.

Note that the Ziegler-Nichols' closed loop method can be applied only to processes having a time delay or having dynamics of order higher than 3.

The Ziegler-Nichols' closed loop method is based on experiments

executed on an established control loop (a real system or a simulated system).

The tuning procedure is as follows:

1.Bring the process to (or as close to as possible) the specified operating point of the control system to ensure that the controller during the tuning is "feeling" representative process dynamic and to minimize the chance that variables during the tuning reach limits. Process is brought to the operating point by manually adjusting the control variable, with the controller in manual mode, until the process variable is approximately equal to the set-point.

2.Turn the PID controller into a P controller by setting set $T_i = \infty$ and T_d. Initially, gain K_p is set to "0". Close the control loop by setting the controller in automatic mode.

3. Increase K_p until there are sustained oscillations in the signals in the control system, e.g. in the process measurement, after an excitation of the system. (The sustained oscillations correspond to the system being on the stability limit.) This K_p value is denoted the ultimate (or critical) gain, K_{pu}. The excitation can be a step in the set-point. This step must be small, for example 5% of the maximum set-point range, so that the process is not driven too far away from the operating point where the dynamic properties of the process may be different. On the other hand, the step must not be too small, or it may be difficult to observe the oscillations due to the inevitable measurement noise. It is important that K_{pu} is found without the control signal being driven to any saturation limit (maximum or minimum value) during the oscillations. If

such limits are reached, there will be sustained oscillations for any (large) value of K_p, e.g. 1000000, and the resulting K_p-value is useless (the control system will probably be unstable). One way to say this is that K_{pu} must be the smallest K_p value that drives the control loop into sustained oscillations.

1. Measure the ultimate (or critical) period Pu of the sustained oscillations.

2. Calculate the controller parameter values according to Table 2, and these parameter values are used in the controller. If the stability of the control loop is poor, stability is improved by decreasingK_p, for example a 20% decrease.

Table 2:3 Ziegler–Nichols tuning method, gain parameter's calculation.

Control Type	KP	Ki	Kd
P	0.5*Ku	-	-
PI	0.45*Ku	1.2*Kp/Tu	-
PID	0.6*Ku	2*Kp/Tu	Kp*Tu/8

3. PID Tuning Software

There is some prepared software that they can easily calculate the gain parameter. Any kind of theoretical methods can be selected in some these methods.

Some Examples: MATLAB Simulink PID Controller Tuning,

2.2.5 Fuzzy Controller

1. Introduction

Accurate control is critical to every process that leads to various types of controllers which are being widely used in process industries. Tuning methods for these controllers are very important for process industries.

The aim of this project is to design a fuzzy logic controller for speed control of a DC motor; Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required.

All control systems suffer from problems related to undesirable overshoot, longer settling times and vibrations and stability while going from one state to another state.

Real world systems are nonlinear, accurate modeling is difficult, costly and even impossible in most cases conventional PID controllers generally do not work well for non-linear systems. Therefore, more advanced control techniques need to be used which will minimize the noise effects. To overcome these difficulties, there are basic approaches to intelligent control: knowledge based expert systems, fuzzy logic, and neural networks.

Fuzzy logic, proposed by Lotfi A. Zadeh in 1973. Zadeh introduced the concept of a linguistic variable.

The fuzzy logic, unlike conventional logic system, is able to model inaccurate or imprecise models.

Fuzzy Logic has been successfully applied to a large number of control applications. The most commonly used controller is the PID controller, which requires a mathematical model of the system. A fuzzy logic controller provides an alternative to the PID controller. The control action in fuzzy logic controllers can be expressed with simple "if-then" rules. Fuzzy controllers are more sufficient than classical controllers because they can cover a much wider range of operating conditions than classical controllers and can operate with noise and disturbances of a different nature.

Fuzzy Logic is a multi-valued logic, that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low and emerged as a tool to deal with uncertain, imprecise, or qualitative decision making problems.

Fuzzy logic is a way to make machines more intelligent to reason in a fuzzy manner like humans. A fuzzy logic model is a logical-mathematical procedure based on an "IF-THEN" rule system that mimics the human way if thinking in computational form.

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system. The fuzzy controller block diagram is given in Figure 1.2, where we show a fuzzy controller embedded in a closed-loop control system. The plant outputs are denoted by y(t), its inputs are denoted by u(t), and the reference input to the fuzzy controller is denoted by r(t).

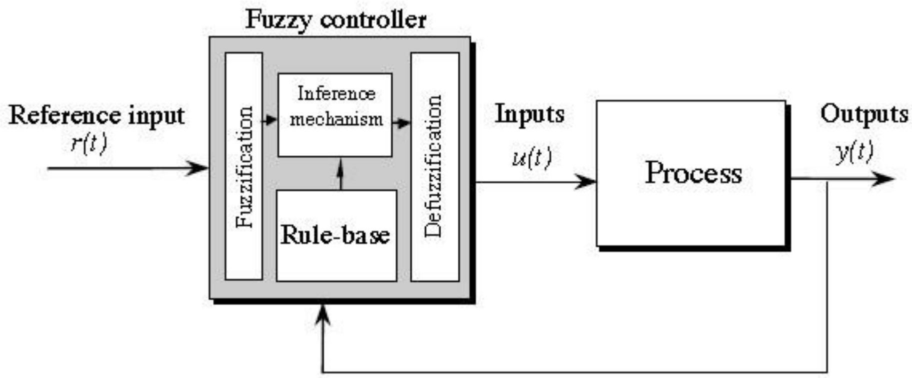


Fig 2.6: Fuzzy controller architecture.

2. Fuzzy Controller component:

The fuzzy controller has four main components:

(1) The “rule-base” holds the knowledge, in the form of a set of rules, of how best to control the system. (2) The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be. (3) The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rulebase. And (4) the defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant.

I. Fuzzification

The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called Fuzzification. In others words, means the assigning of linguistic value, defined by relative small number of membership functions to variable.

II. Fuzzy inference

Under inference, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Mostly MIN or PRODUCT is used as inference rules. In MIN inference, the output membership function is clipped off at a height corresponding to the rule premise's computed degree of truth (fuzzy logic AND). In PRODUCT inference, the output membership function is scaled by the rule premise's computed degree of truth.

III. Rule base

For the rule bases a classic interpretation of Mandani was used. Under rule base, rules are constructed for outputs. The rules are in “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller could be implemented using conventional techniques.

- Rules Format:

Basically a linguistic controller contains rules in the IF-THEN format, but they can be presented in different formats. In many systems, the rules are presented to the end-user.

- Connectives:

In mathematics, sentences are connected with the words OR, AND, IF-THEN and if and only if, or modifications with the word NOT.

- Modifiers:

A linguistic modifiers, is an operation that modifies the meaning of a term. For example, in the sentence ‘‘very close to 0’’, the word **very** modifies close to 0 which is a fuzzy set. A modifier is thus an operation on a fuzzy set.

The modifier very can be defined as squaring the subsequent membership function.

IV. Defuzzification

Defuzzification is a process in which crisp output is obtained by the fuzzy output. In other words, process of converting fuzzy output to crisp number there is more common techniques are the CENTROID and MAXIMUM methods. In the CENTROID method, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function for the fuzzy value. In the MAXIMUM method, one of the variable values at which the fuzzy subset has its maximum truth value is chosen as crisp value for the output variable.

3.3 Fuzzy Controller Design:

Fuzzy control system design essentially amounts to (1) choosing the fuzzy controller inputs and outputs, (2) choosing the preprocessing that is needed for the controller inputs and possibly post processing that is needed for the outputs, and (3) designing each of the four components of the fuzzy controller, there are standard choices for the fuzzification and defuzzification interfaces. Moreover, most often the designer settles on an inference mechanism and may use this for many different processes. Hence, the main part of the fuzzy controller that we focus on for design is the rule-base.

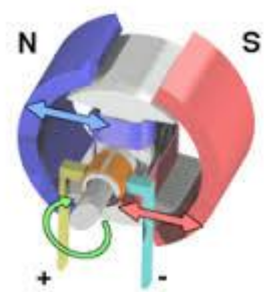
The rule-base is constructed so that it represents a human expert "in-the loop."

Hence, the information that we load into the rules in the rule-base may come from an actual human expert who has spent a long time learning how best to control the process. In other situations there is no such human expert, and the control engineer will simply study the plant dynamics (perhaps using modeling and simulation) and write down a set of control rules that makes sense.

Basically, you should view the fuzzy controller as an artificial decision maker that operates in a closed-loop system in real time. It gathers plant output data y(t), compares it to the reference input r (t), and then decides what the plant input u(t) should be to ensure that the performance objectives will be met. To design the fuzzy controller, the control engineer must gather information on how the artificial decision maker should act in the closed-loop system. Sometimes this information can come from a human decision maker who performs the control task, while at other times the control engineer can come to understand the plant dynamics and write down a set of rules about how to control the system without outside help. These “rules” basically say, “If the plant output and reference input are behaving in a certain manner, then the plant input should be some value.” A whole set of such “If-Then” rules is loaded into the rule-base, and an inference strategy is chosen, then the system is ready to be tested to see if the closed-loop specifications are met.

CHAPTER THREE

SYSTEM DESIGN



CHAPTER THREE

SYSTEM DESIGN

3.1 Research Methodology

The following Modeling steps shown that steps of controlling DC motor speed with the two controllers, starting from mathematical models, designing in mathlab environment, tuning prameters, analyze results and investigate with expected ones, until get accessible results.

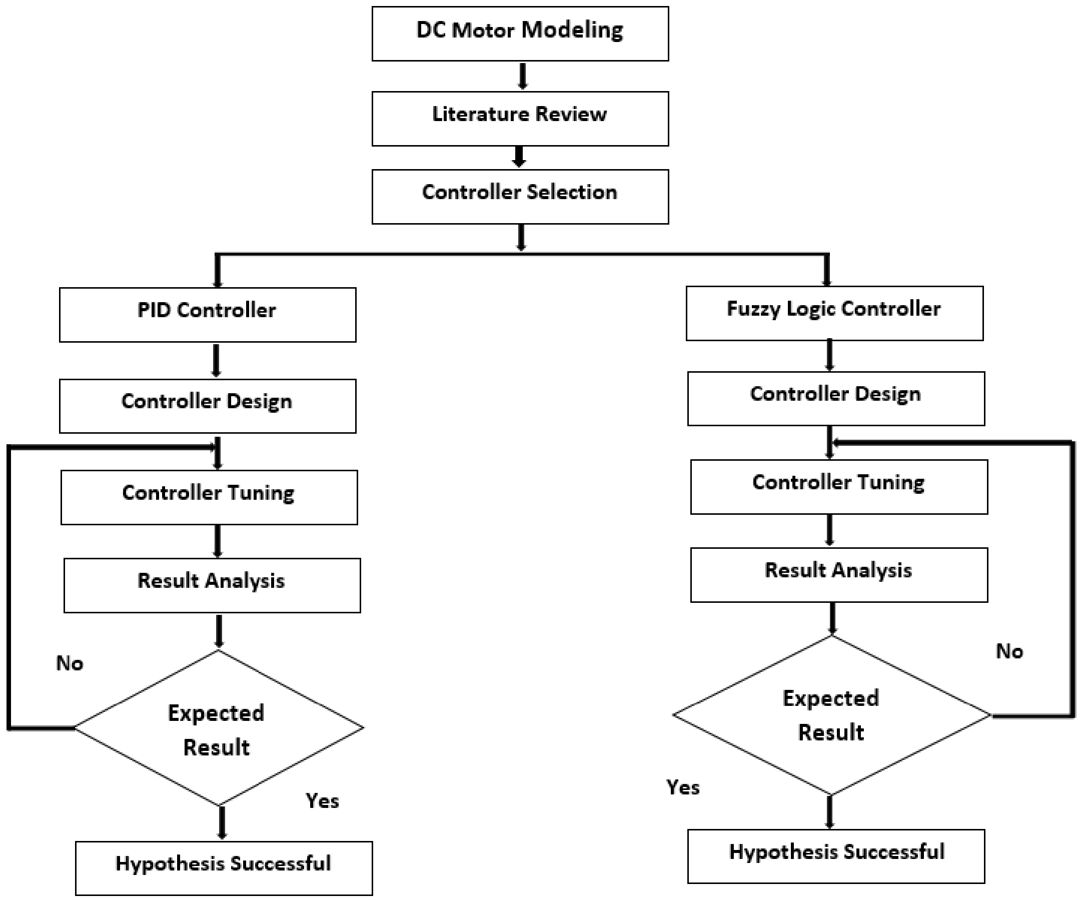


Fig. 3.1: Modeling Steps

3.2 DC MOTOR MODELLING

The DC motor modeling is done summing the torques acting on the rotor inertia and integrating the acceleration to the velocity and also Kirchhoff's laws to armature circuit.

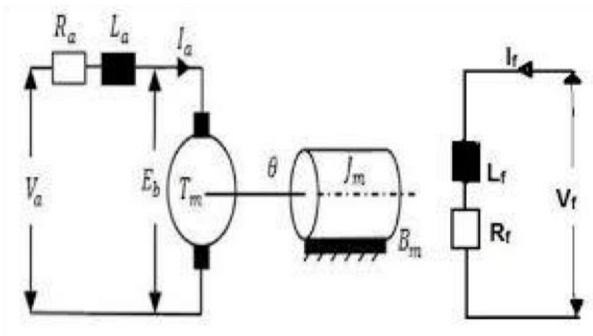


Fig3.2: Dynamic Motor Model

The mathematical model of DC motor can be constructed by suing four basic equations of motor.

- In an armature current controlled DC motor, the field current i_f is held constant, and the armature current is controlled through the armature voltage V_a.
- The motor torque increases linearly with the armature current.

$$T_m(t) = k_i i_a(t) \quad (1)$$

- k_i Is a constant that depends on a given motor .The transfer function from the input armature current to the resulting motor torque is

$$\frac{T_m(s)}{i_a(s)} = k_i$$

- The voltage/current relationship for the armature side of the motor is

$$V_a(t) = V_R + V_l(t) + V_b$$

$$V_a(t) = R_a i_a(t) + \frac{l_a di_a}{dt} + e_b(t) \qquad (2)$$

$$V_a(t) - e_b(t) = R_a i_a(t) + \frac{l_a di_a}{dt}$$

- V_b Represents “the back EMF” induced by the rotation of the armature windings in a magnetic field. V Is proportional to the speed□.

$V_b(s) = k_b \omega(s)$ (3)

- An equation describing the rotational motion of the inertial load is found by summing moments

$$\sum M = T_m - Bw = J\frac{dw}{dt}$$

$$T_m(t) = J\frac{dw}{dt} + Bw(t) \qquad (4)$$

- The transfer function from the input motor torque to rotational speed changes is

$$\frac{\omega(s)}{T_m(s)} = \frac{1/J}{s+c/J} \qquad 1^{st}\ order \qquad (5)$$

Taking Laplace transforms of Equation (2) gives

$$V_a(s) - V_b(s) = (R_a + l_a s)\ i_a(s) \qquad (6)$$

Assuming physical parameters of the motor:

J: Moment of inertia of the rotor 0.068 kg/m2

B: Motor viscous friction constant 0.03475NM/rad. sec

K_b: Electromotive force constant 3.475V/rad/sec

K_t: Motor torque constant 3.475 N .m/Amp

R_a: Electric resistance 7.56 Ohm

L_a: Motor Inductance 0.055 H

L_f : Friction Torque 0.212N-m

T = Time constant 40msec

3.3 TRANSFER FUNCTION OF DC MOTOR

The transfer function of DC Motor is derived by simplifying four basic equations and applying Laplace transform. Here we will take that the input of the system is the reference voltage (V) applied to the motor's armature, while the output is the rotational speed of the shaft (W_R).

Equations (1), (5) and (6) together can be represented by the closed loop block diagram shown below.

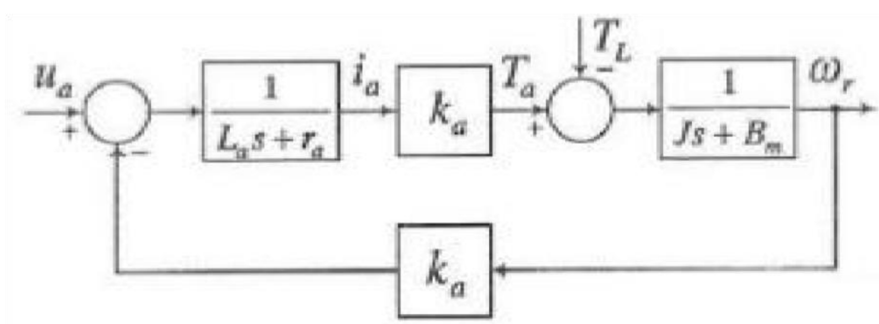


Fig3.3: Block diagram

Block diagram reduction gives the transfer function from the input armature voltage to the resulting speed change.

$$\frac{\omega(s)}{V_m(s)} = \frac{k_i/L_aJ}{\left(s+\frac{R_a}{L_a}\right)\left(s+\frac{c}{J}\right)+K_bK_i/L_aJ} \qquad 2^{nd}\ order \qquad (7)$$

If we assume the time constant of the electrical circuit is much smaller than the time constant of the load dynamics, the transfer function of

Equation (6) may be reduced to a first order transfer function

$$\frac{\omega(s)}{V_m(s)} = \frac{k_i/L_aJ}{s+(cR_a+K_bK_i)/R_aJ} \qquad 1^{st}\ order \qquad (8)$$

The transfer function from the input armature voltage to the resulting angular position change is found by multiplying Equations (7) and (8) by 1/s.

3.4 PID Controller Modelling System

3.4.1 PI Controller Design

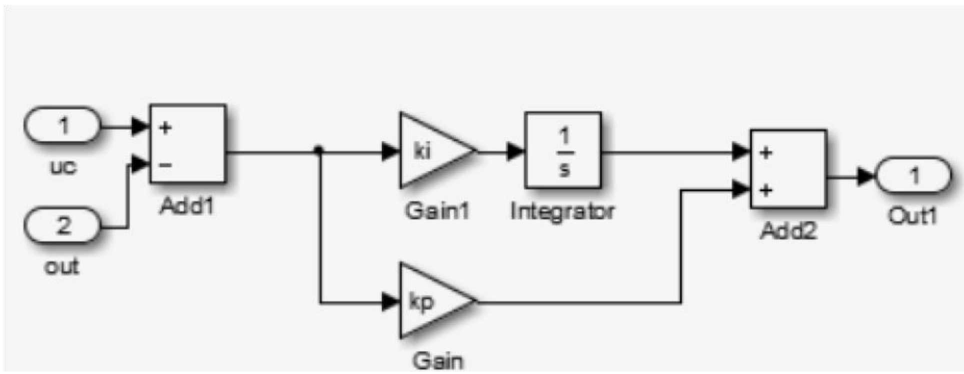


Fig3.4: PI Controller Design

To obtain the optimum gain value for Kp, Ki and Kd, several gain value have been tested. The best combinations of gain value are when the system can run with the minimum overshoot, minimum steady state error and minimum steady state time.

3.5 Fuzzy Logic Controller Design

3.5.1 Designing procedure

This project presents a methodology for rule base fuzzy logic controller applied to a system. Before running the simulation in MATLAB/SIMULINK, the Fuzzy Logic Controller is to be designed. This is done using the FIS editor. FIS file is created using the Fuzzy logic toolbox. The design of a Fuzzy Logic Controller requires the choice of Membership Functions. After the appropriate membership functions are chosen, a rule base is created. The set of linguistic rules is the essential part of a fuzzy controller. The various linguistic variables to design rule base for output of the fuzzy logic controller are enlisted in Table I. The response of the fuzzy logic controller is obtained using in MATLAB / SIMULINK. A two input which is Speed Error (e) & Change in Error (ec) and one –output Change in control, fuzzy controller is created and the membership functions and fuzzy rules are determined. The membership functions (MF) for inputs are shown below in Fig. 3.5, 3.6 and the MF for output is shown in fig. 3.7.

The design of FLC tested in this project stated as:

Fuzzy Logic Controller (5x5) matrix.

In order to develop the Fuzzy Logic Controller, FLC toolbox in Simulink has been used. Below are general setting parameter and method has been used for FLC controller (5x5).

- Fuzzy Input:

    i. Error of speed (5 membership)

    ii. Change of speed error (5 membership)

- Fuzzy Output:
    i. Control output (5 membership)

- Fuzzy Inference System: Mamdani

- Defuzzification Method: Centroid
- Rules Base: 25 rules

Table3.1: Linguistic variables

HN	LN	ZE	LP	HP
High negative	Low negative	Zero	Low positive	High positive

Table 3.2: Rule base for fuzzy logic controller.

E \ CE	HN	LN	ZE	LP	HP
HP	ZE	LP	HP	HP	HP
LP	LN	ZE	LP	HP	HP
ZE	HN	LN	ZE	LP	HP
LN	HN	HN	LN	ZE	LP
HN	HN	HN	HN	LN	ZE

For the fuzzy logic controller the input variables are error (e) and rate (change) of error (Δe), and the output variable is controller output (Δv). Triangular membership functions are used for input variables and the output variable. Each variable has 5 membership functions. Thus, there were total 25 rules generated. The universe of discourse of error, rate of error and output are [0, 1], [0,1] and [0,1] respectively. The rule base framed for DC motor is tabulated in Table 2. The structure of the rule base provides negative feedback control in order to maintain stability under any condition. Linguistic variables for error, rate of error and controller output are tabulated in table 1[8].

Fig 5, 6, 7 and 8 shows membership functions of different variables implemented in FIS editor in MATLAB toolbox.

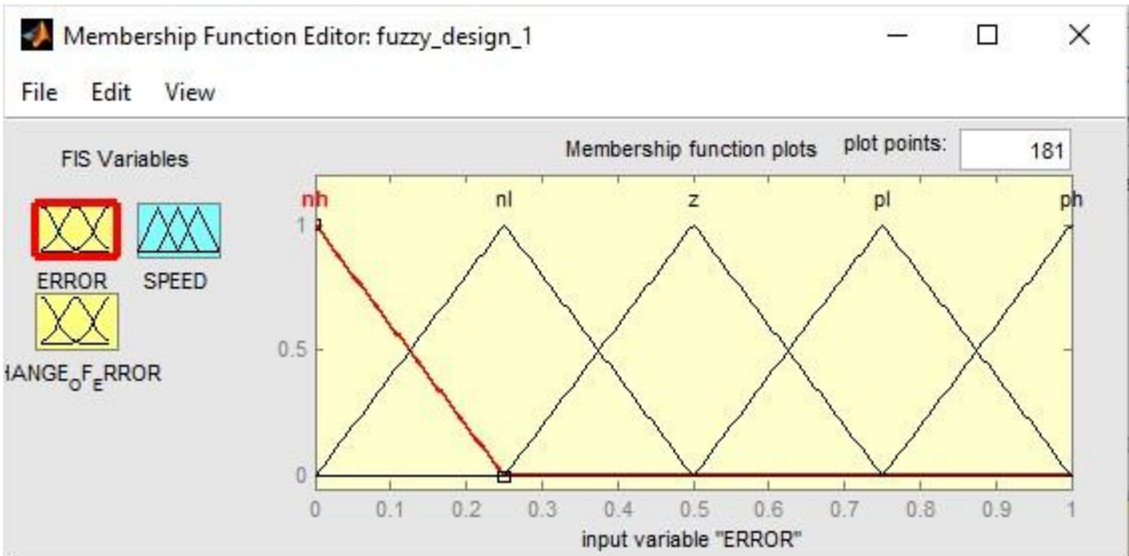


Fig 3.5: Membership functions for input-1(error)

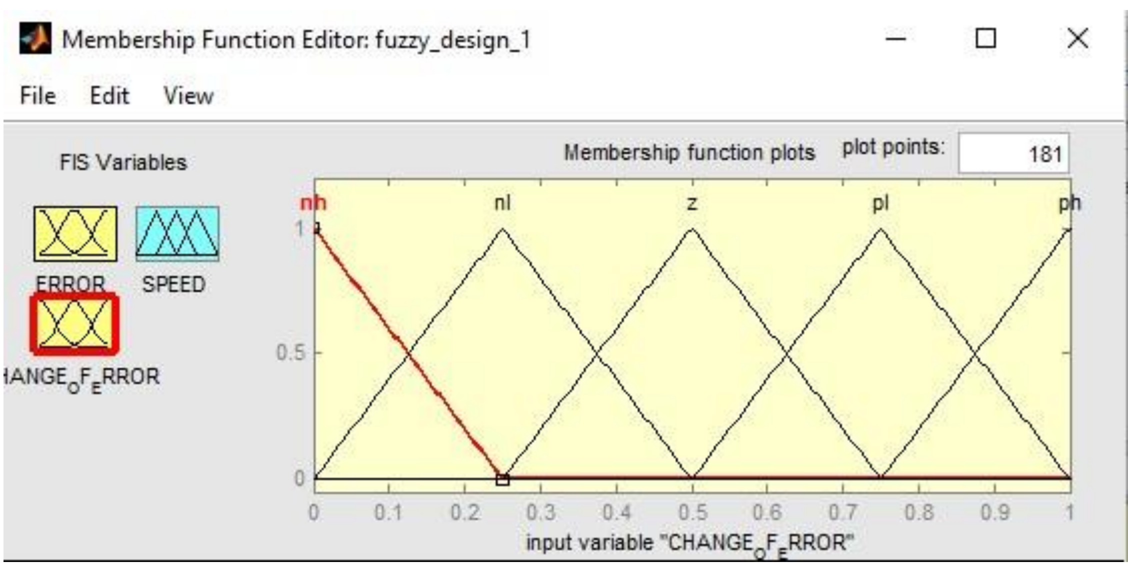


Fig 3.6: Membership functions for input-2(change of error)

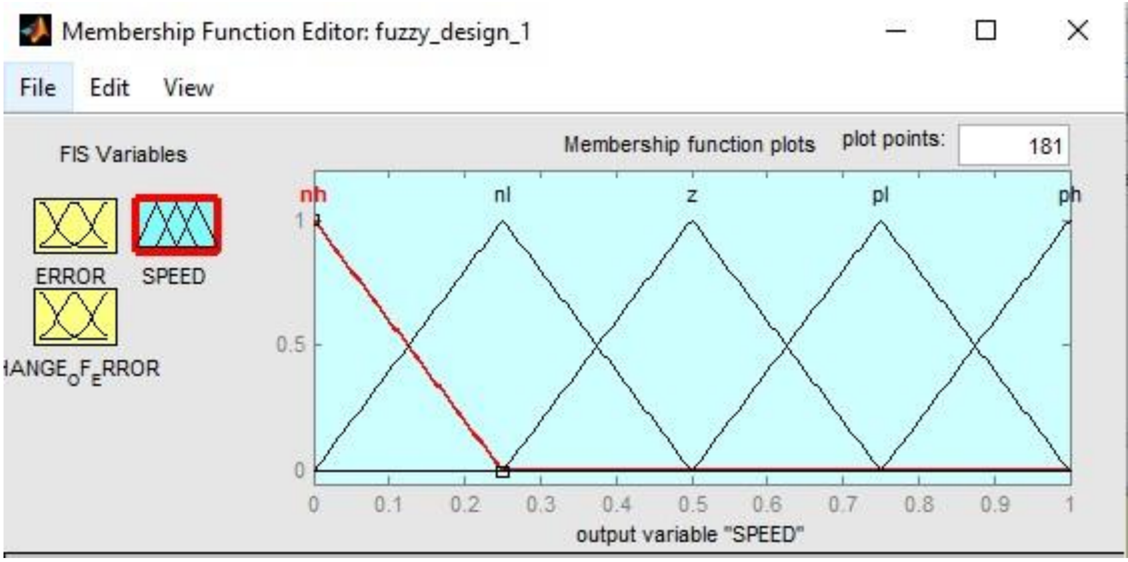


Fig 3.7: Membership functions for output.

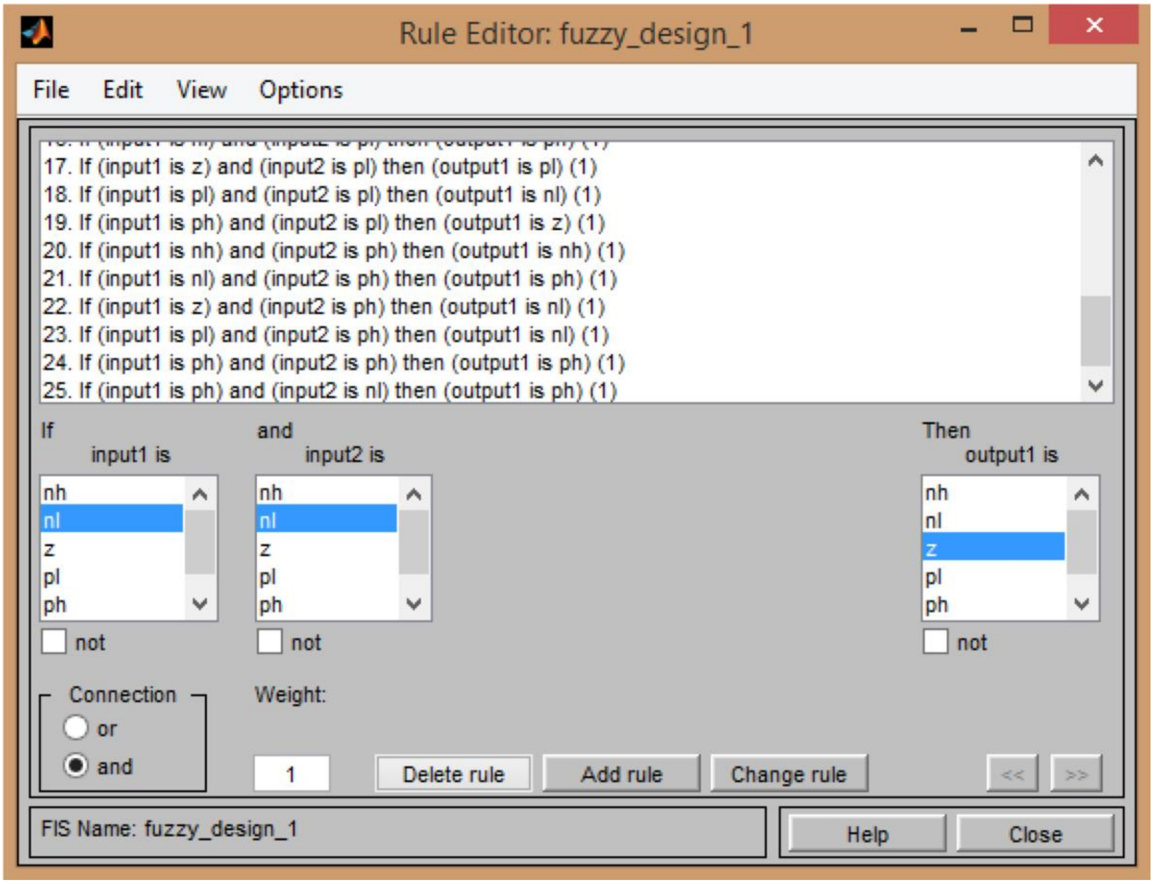


Fig.3.8: Fuzzy if-then rules

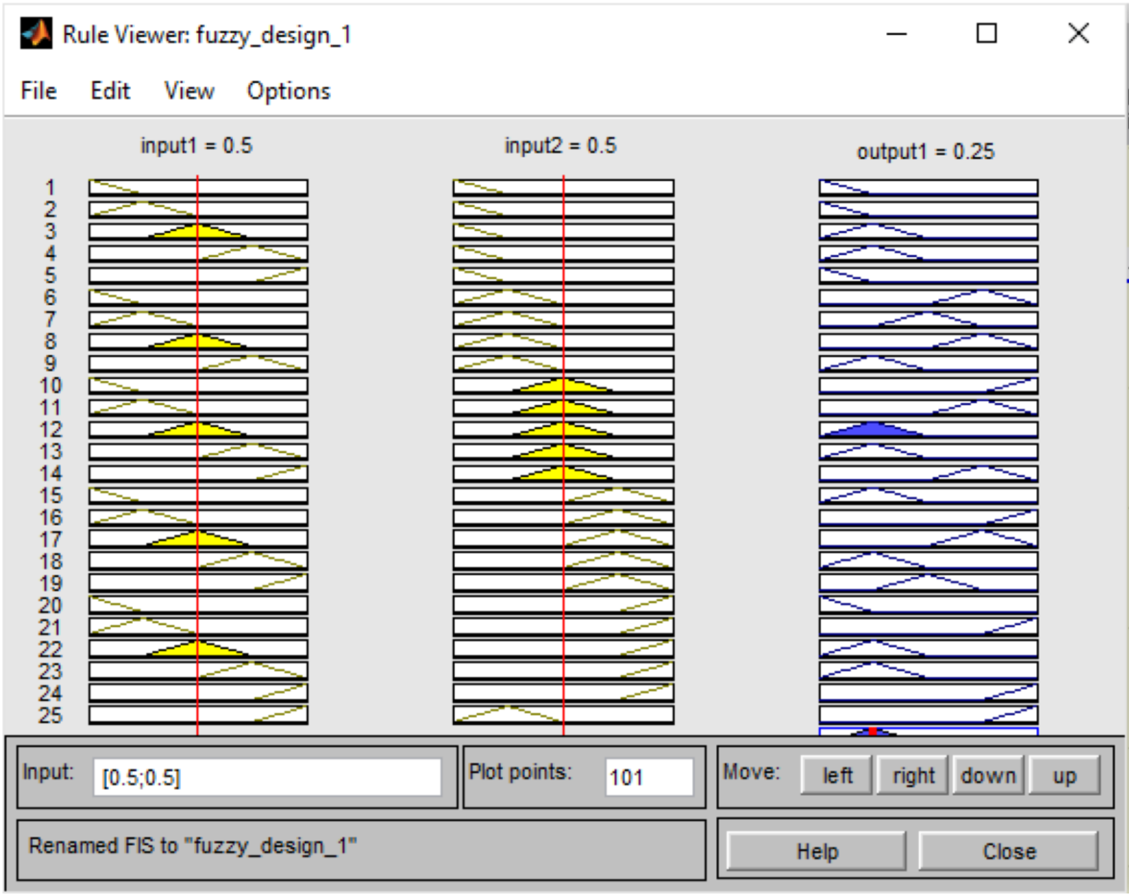
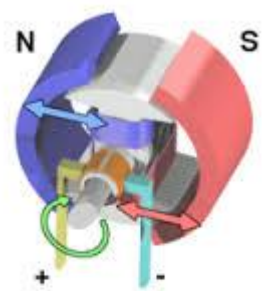


Fig.3.9: Analysis of both inputs and outputs

CHAPTER FOUR

SIMULATION



CHAPTER FOUR

SIMULATION

4.1 Background

The simulations for different control mechanism discussed above were carried out in Simulink in MATLAB and simulation results have been obtained.

1. **PID Controller**

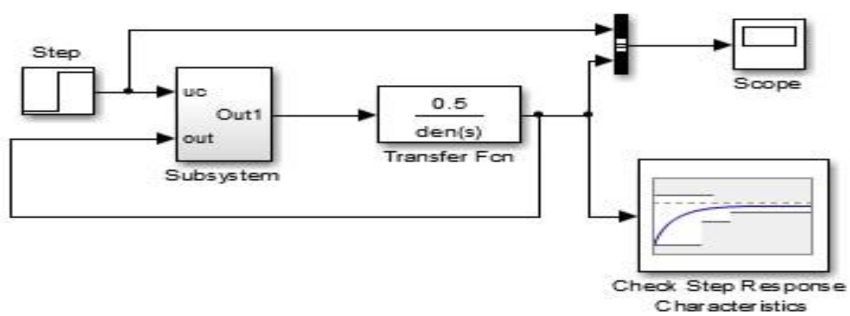


Fig 4.1: PID Controller Simulink model

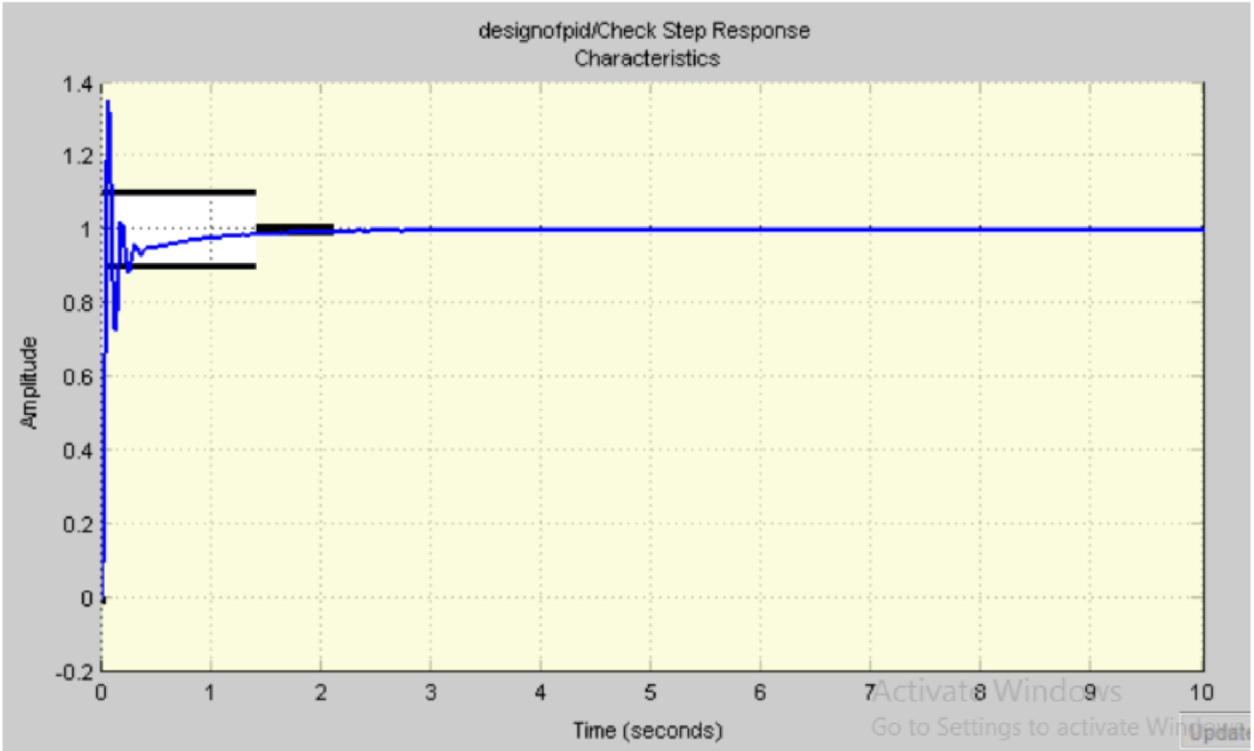


Fig 4.2: Unit step response of PID Controller

2. *Fuzzy logic controller*

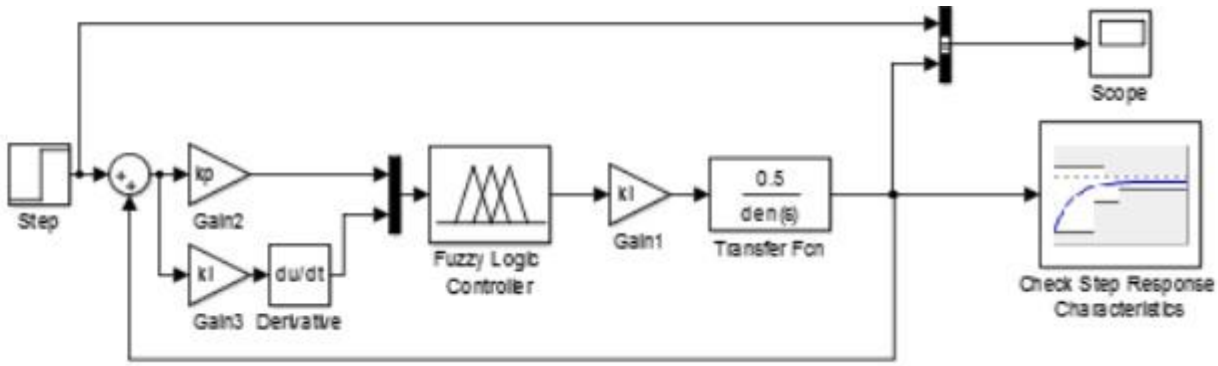


Fig.4.3: Fuzzy Logic Controller Simulink model

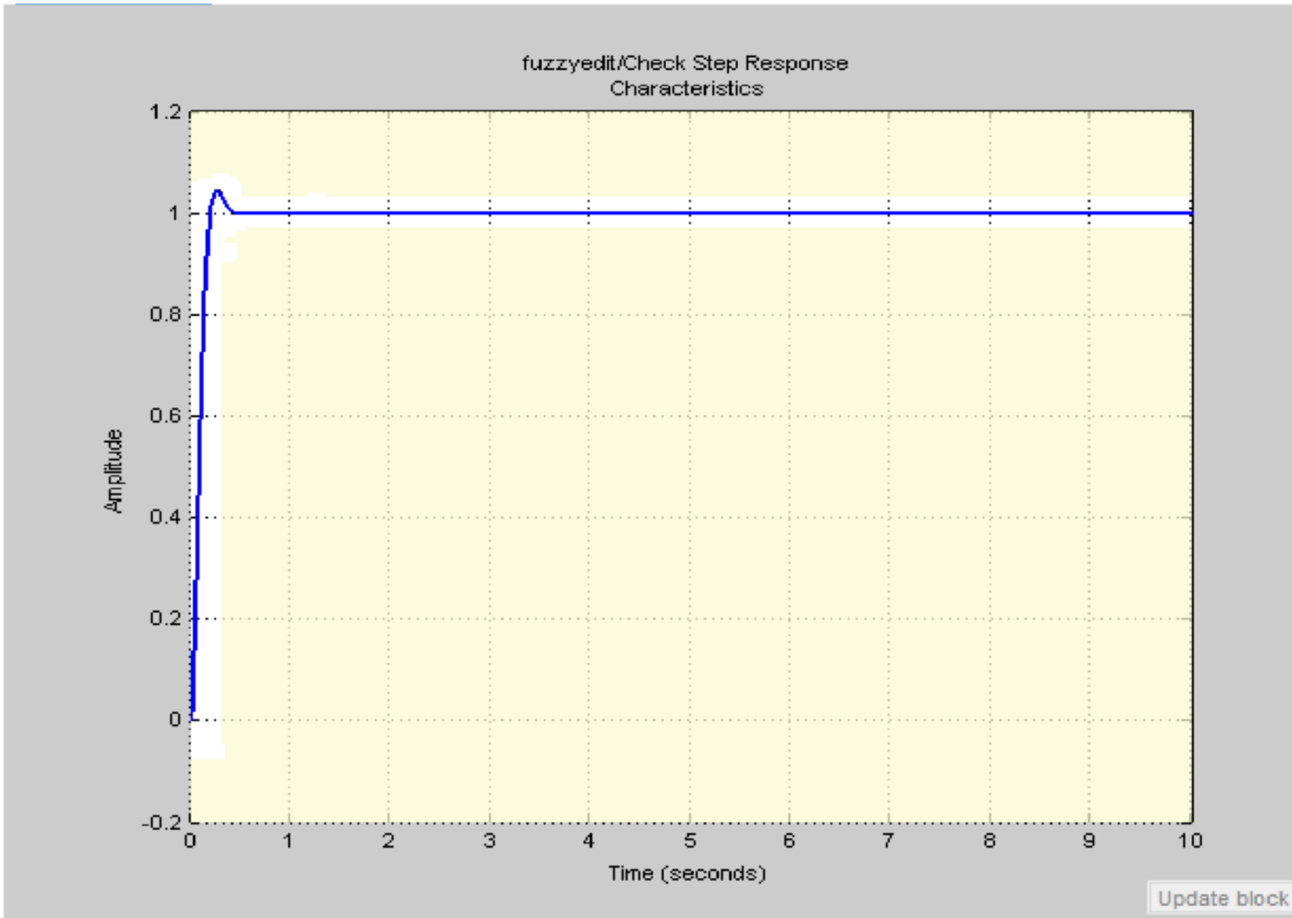


Fig 4.4: Unit step response of fuzzy logic Controller

3. Comparative step response for PID regulated system and FLC controlled system is shown in figure 5.

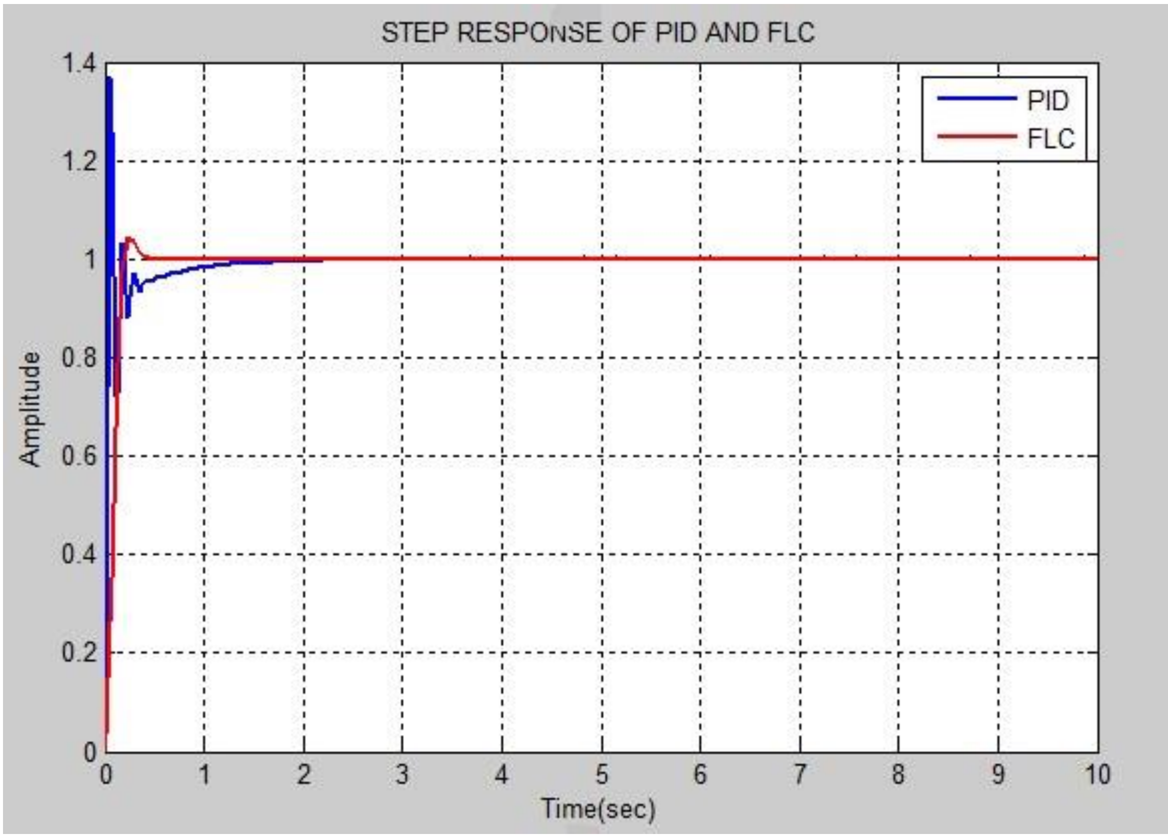


Fig.4.5: Step responses of system using PID and fuzzy logic controller

Figure (5) shows that the response of the system has greatly improved on application of fuzzy logic controller (FLC). The overshoot of the system using FLC has been reduced, settling time, peak time of the system also shows appreciable reduction as analyzed in Table (1).

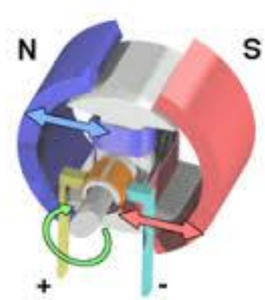
Table 4.1COMPARISON BETWEEN THE OUTPUT RESPONSES FOR CONTROLLERS

Title	**PID Controller (x)**	**Fuzzy Logic Controller** (y)	**∆%** **y-x/x *100**
Rise Time(sec)	**0.0286**	**0.1270**	**44.40%**
Peak Time(sec)	**1.0763**	**1.0416**	**-3.22%**
Settling Time(sec)	**1.3950**	**0.3362**	**-75.89%**
Overshoot%	**39.5190**	**4.3867**	**-88.89%**

***The sign in indication increase or decrease.**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION



CHAPTER FIVE

1. CONCLUSIONS

In his project the speed of a DC motor is controlled using fuzzy logic and PID controller. The simulation results are obtained using MATLAB/SIMULINK. The fuzzy logic response is compared with that of conventional PID controller. The results show that the overshoot, settling time, peak time and control performance has been improved greatly by using Fuzzy Logic controller. The proposed fuzzy Logic controller has more advantages, such as higher flexibility, control, better dynamic and static performance compared with conventional controller. Hence, Fuzzy logic controller design was proposed and simulated.

Then The utilization of Fuzzy logic control show that the over shot was improved (89%) ,settling time with (76%),and peak time(3%) ،Which improve the performance characteristic. Although the Rise time increase (44%).

2. RECOMINDATION

The development of dc motor performance in The Fuzzy Logic control need additional control technique to enhance Rise time then it will be complete solution for DC motor performance.

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