POSITION CONTROL OF DC MOTOR BY SELF TUNED FUZZY PID CONTROLLER

Thesis submitted towards the partial fulfillment of the requirements of the degree

of

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in

Power Systems& Electric Drives

Submitted by

Barjinder Singh
(Regd. No. 801041006)

Under the supervision of

Mrs.Suman Bhullar
Assistant Professor, EIED

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ELECTRICAL & INSTRUMENTATION ENGINEERING DEPARTMENT
THAPAR UNIVERSITY, PATIALA
(Established under section 3 of UGC act 1956)
PATIALA – 147004

CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled **"Position control of DC motor by self tuned Fuzzy PID controller"**, in partial fulfillment of the requirements for the award of degree of Master of Engineering in Power Systems & Electric Drives submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Mrs. Suman Bhullar, Assistant Professor, EIED.

The matter presented in the thesis has not been submitted for the award of any other degree of this or any other university.

Barjinder Sgh.
Barjinder Singh
(Roll No: 801041006)

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Bhullar
Mrs. Suman Bhullar
Assistant Professor,

Countersigned by:

S. Ghosh
Dr. Smarajit Ghosh
Professor & Head, EIED
Thapar University, Patiala

Dr. S. K. Mohapatra
Dean of Academic Affairs
Thapar University, Patiala

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Date: **(Barjinder Singh)**

Place: Thapar University, Patiala

Abstract

Both DC and AC motors have been extensively used in control systems but each has its own characteristics. The main advantages of DC motors are easy speed and position control. DC motors have become the preferred choice in many industrial applications such as robot control, welding, roll process, etc. There is a strong interest to develop new control tools to enhance their performance and their intelligence. The aim of this thesis is to design a robust method of position control of DC motor.

There are three kinds of DC motor position control: Classic method such as PID controllers in which the big limitation can be seen if the parameter of the system is changed, modern style such as adaptive controller which is time consuming as identification process is added to the process and intelligent method as fuzzy controller and neural networks show better performance. As new researches show, the fuzzy controllers give a good performance in the presence of noise.

In this thesis we take three controller PID controller, Self tuned Fuzzy PID controller and Two self tune Fuzzy PID controller. Comparison of the different kinds of controllers are analyzed in the thesis. It was found that the proposed controller overcome uncertainly and reduces the error..

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	Alternative current
AI	Artificial intelligence
EMF	Electromotive Force
DC	Direct Current
EMF	Electromotive Force
K_p	Proportional gain, a tuning parameter
K_i	Integral gain, a tuning parameter
K_d	Derivative gain, a tuning parameter
P	Proportional
FL	Fuzzy logic
FLC	Fuzzy logic controller
MF	Membership Funtion
PI	Proportional- Integral
PID	Proportional- Integral- Derivative
SSE	Steady state error
Z- N	Zeigler & Nichols

CHAPTER 1 Introduction

1.1 Introduction

In today’s world, almost all land-based electrical power supply networks are AC systems of generation, transformation, transmission and distribution. Thus there is little need for large DC generators. A DC machine can operate as either a generator or a motor but at present its use as a generator is limited because of the widespread use of AC power. Large DC motors are used in machine tools, printing presses, conveyors, fans, pumps, hoists, cranes, paper mills, textile mills and so forth. Small DC machines (in fractional horsepower rating) are used primarily as control devices such as tacho-generators for speed sensing and servomotors for positioning and tracking. DC motors still dominate as traction motors used in transit cars and locomotives as the torque-speed characteristics of DC motor can be varied over a wide range while retaining high efficiency. The DC machine definitely plays an important role in industry.

1.2 Methodology used

In brief, the methodology employed goes along as following steps

Step 1 The modelling of a DC motor is done through different steps like represent the DC motor circuit diagram, its system equations, calculating transfer function.

Step 2 The control algorithms are converted to model block using MATLAB/SIMULINK.

Step 3 Simulation of Fuzzy Self Tuned PID Controller

Step 4 In this step, position control of DC motor is done. First we use conventional controller like PID design by Zeigler and Nichols method, then Fuzzy self tune PID controller and then we use two Fuzzy self tune PID controller, results of these are compared and analyzed.

1.3 Literature Review

ohishi *et al.* [24] proposed observer theory and it was programmed in the microprocessor. The deadbeat observer could estimate the sum of all the external forces quickly with a very simple structure.

Paul and Bandyopadhyay[25] discussed an algorithm for ideal sliding mode control of low inertia motor . The algorithm was successfully tested through simulation as well as practical implementation.

Azevedo ***et al.*** **[3]** presented an application of Fuzzy logic to control the position of a load coupled to the output shaft of a gearbox The prime mover of the gearbox was a dc machine which was supplied by a chopper circuit The elaboration and tuning of the fuzzy logic controller (FLC) was based on a sliding mode control approach.

Hai Lin ***et al.*** **[4]** they compared The fuzzy logic and proportional-integral-derivative (PID) controllers. Fuzzy rules and inferenceing mechanism of the FLC were evaluated in real-time instead of using conventional rule-lookup tables that encode the control knowledge in a numerical form. The performance assessment of the studied position controllers was based on accuracy, resolution and settling time to changes in the command signals. It is shown that the FLC is performed better than the PID controller. The hardware and software of PID and fuzzy logic position controllers were also presented.

Baek and Kuc [5] proposed an adaptive PID learning controller which consists of a set of learning rules for PID gain tuning and learning of an auxiliary input. The proposed PID learning controller was shown to drive the state of uncertain DC motor system with unknown system parameters and external load torque to the desired one globally asymptotically. Computer simulation and experimental results were given to demonstrate the effectiveness of the proposed PID learning controller.

Hong.J [13] described a neural network-based adaptive control strategy for speed or position tracking of a DC motor with unknown system nonlinearities. In the proposed scheme, they integrate some existing techniques, such as the input output linearization technique used to cancel the nonlinearities, and neural networks used to implement the control law. The network approximation errors was compensated by using the sliding mode control scheme.

Tang. J [28] addresses real-time DC motor speed and position control using the low-cost TMS320C31 digital signal processing starter kit (DSK). A PID controller was designed using MATLAB functions to generate a set of coefficients associated with a desired controller's characteristics. The controller coefficients were then included in an assembly language program that implements the PID controller. Code Explorer was used to load and run the PID controller to achieve real-time control.

Zadeh ***et al*** **[36]** proposed the use of sliding mode control. SMC is not sensitive to changes.. One of the most important deficiencies was that the controller parameters were constant. They achieved better response by SMC in comparison with classical methods in terms of shorter settling time, less overshoot and more stability.

Montiel *et.al.* [22] presented an innovative method called Simple Tuning Algorithm (STA) for tuning fuzzy controllers, it had only one variable to adjust to achieve the tuning goal, that in counterpart to other methods like the PID controller which had three variables to adjust for the same goal.

Koksal and Yenici [18] described that the motor parameters change under operation according to several conditions. Therefore, the performance of controller, which has been designed considering constant motor parameters become poorer. For this reason, a model reference adaptive control method was proposed to control the position of a dc motor without requiring fixed motor parameters

Fallahi and Azadi [11] used high control gain to overcome uncertainties lead to occur chattering phenomena in control law which could excite unmodeled dynamics and might be harm the plant. In order to enhancement the sliding mode controller performance, they had used fuzzy logic. For this purpose, they had used a PID outer loop in the control law then the gains of the sliding term and PID term was tuned on-line by a fuzzy system, so the chattering was avoided and response of the system was improved against external load.

Ananthababu and Reddy [15] presented the comparison of tracking performance of fuzzy PI controller with conventional controller to control PMDC Motor which employs only two fuzzy sets on the universe of discourse of each input variable and three fuzzy sets on the universe of discourse of output variable.

Karimipour and Shandiz [16] presented that position of a DC motor was controlled by using scaling factor and switching between two fuzzy controllers automatically. In simulation, variations of load and armature voltage were applied and the result showed that controller overcome chattering successfully.

Thomas and Poongodi [29] design a position controller of a DC motor by selection of a PID parameters using genetic algorithm. The model of a DC motor was considered as a third order system. And they compared two kinds of tuning methods of parameter for PID controller. It was found that the proposed PID parameters adjustment by the genetic algorithm was better than the Ziegler & Nichols' method.

Bakly *et al.* [4] presented a DC motor sliding mode position controller design using fuzzy logic (FL) and proportional-integral-derivative (PID) techniques. The FL wasl considered in the design of SMC. Also, a PID was used in the outer loop in the control law then the gains of the sliding term and PID term were tuned on-line by a fuzzy system, so the chattering was avoided and response of system was improved against external load .

Castaneda and Mancilla [6] describe an adaptive discrete-time tracking controller for a direct current (DC) motor with controlled excitation flux. A high order neural network was used to identify the plant model. That network was trained with an extended Kalman filter. Then, the discrete-time block control and sliding mode techniques were used to develop the reference tracking control for the angular position of a DC motor with separate winding excitation. The scheme was illustrated via simulations.

Yongxin and Wang [34] presented a self tuning PID controller. The controller was simulated on Matlab Simulink. The simulation result showed the difference of conventional PID controller and the parameters self-tuning fuzzy PID. From those simulation results, all performance indexes of the fuzzy PID controller with parameters self-tuning were vastly superior to those of the conventional PID controller.

Cavalcanti [9] proposed the design, implementation details and experimental results of an intelligent control system developed for adaptive control of a dynamic system represented by a d.c. motor. The system was based on PID and neural network and uses fuzzy rules to switch between the two controllers.

Altayef and Qun-xiong [2] presented the position control of a DC motor using Fuzzy Logic and PID Control logarithms .Fuzzy Logic and PID controllers were designed based on labview program, and the real - time position control of the DC motor was realized by using DAQ device. The experimental results demonstrate that the responses of DC motor with FLC showed a satisfactory, well damped control performance.

jamal and zhu [14] presented the position control of a DC motor using Fuzz Logic and PID Control algorithms .Fuzzy Logic and PID controllers were designed based on labview program, and the real - time position control of the DC motor was realized by using DAQ device.

Morteza Moradi *et al.[*22] proposed two methods for position contro, LQR method and feedback linearization. We show that these methods without load torque were stable, but, when load is added to the motor's shaft, LQR and feedback linearization could not make efficient input signal for reference tracking in output. To solve this problem, they combined these methods and show by using combined method, the position of shaft tracks reference in presence of large torque. For validation of new controller, they compared response with LQR and feedback linearization.

Duman *et al.* [10] proposed a new search heuristic called Gravitational Search Algorithm (GSA) to determination of the optimal PID controller parameters in the speed and position control of a DC motor.

Rajeswari *et al.* [26] proposed a method of estimating and controlling the speed using PID and Fuzzy for a separately excited DC motor. To achieve accurate speed control of separately excited DC Motor, the rotor speed of the dc motor could be made to follow an arbitrarily selected range especially when the motor and load parameters were known. They tried to implement fuzzy logic control technique to achieve stability by generating control signal for speed with lesser time delay compared to the conventional PID system.

Chang and Gang [8] proposed a EP algorithm with the PID control design to solve the positioning control problem of a PM dc motor, such that a performance index of integrated-absolute error was minimized. PM dc motor position control system was used for proposed method. simulation results of proposed method were presented.

Wang.H in [31] in 2011 suggested, a fast fuzzy controller which was implemented in an FPGA chip ws used for the position control of DC motor. The technique of parallel architecture, direct computation and combinational circuit was adopted for the design of controller. In order to simplify the operation of input firing, they adopted the triangular membership function as the fuzzy sets for antecedence part. The firing strength of those triggered fuzzy rules were calculated through the parallel processing, when dealing with the fuzzy inference.

Weibing and Guanghua [32] studied the fuzzy control and the neural network theory and they present a single neuron fuzzy self-adaptive PID control algorithm for speed control of the brushless DC motor. The Matlab software simulation results show that the single neuron fuzzy self-adaptive PID control algorithm has more robustness, faster response speed and more excellent adaptive capacity than increment PID and PID based on quadratic performance index learning algorithm of single neuron adaptive.

KhajorntraIdet and and Srisertpol [16] presented a technique for estimate load torque of position control system via adaptive torque compensation with observer. Estimation of DC motor load torque by using adaptive compensation method was presented. The results of the study could be used to improve and develop efficiency of the observer. The error of speed and current from estimation process of observer could be reduced.

1.4 Objective of the thesis

Objective of the thesis is to find a controller for position control of DC motor To fill this objective SIMULINK model is used.

1.5 Thesis Layout

The thesis is organised into six chapters. The organisation of thesis is as follow:

Chapter 1: This chapter summarize the brief introduction of DC Motor, methodology used, literature review, objective and thesis layout.
Chapter 2: This chapter describes DC motor and Position control.
Chapter 3: This chapter include theory of Fuzzy logic and Fuzzy logic controller.
Chapter 4: This chapter include the theory of Self Tuned Fuzzy PID controller.
Chapter 5: This chapter include simulation & Results
Chapter 6: This chapter presents Results & Comparisons.

2.1 History of DC motor

2.1.1 Faraday’s motor

Faraday's greatest work was with electricity. In 1821, soon after the Danish chemist, Hans Christian Orsted, discovered the phenomenon of magnetism.

Fig 2.1 Faraday’s Electric Motor

He went on to build two devices to produce what he called electromagnetic rotation which is a continuous circular motion from the circular magnetic force around a wire. A wire extending into a pool of mercury with a magnet placed inside would rotate around the magnet if charged with electricity by a chemical battery. This device is known as a homopolar motor. These experiments and inventions form the foundation of modern electromagnetic technology.

2.1.2 Joseph Henry’s motor

It took ten years, but by the summer of 1831 Joseph Henry had improved on Faraday's experimental motor. Henry built a simple device whose moving part was a straight electromagnet rocking on a horizontal axis. Its polarity was reversed automatically by its motion as pairs of wires projecting from its ends made connections alternately with two electrochemical cells. Two vertical permanent magnets alternately attracted and repelled the ends of the electromagnet, making it rock back and forth at 75 cycles per minute. Henry considered his little machine to be merely a "philosophical toy," but nevertheless believed it was important as the first demonstration of continuous motion produced by magnetic attraction and repulsion.

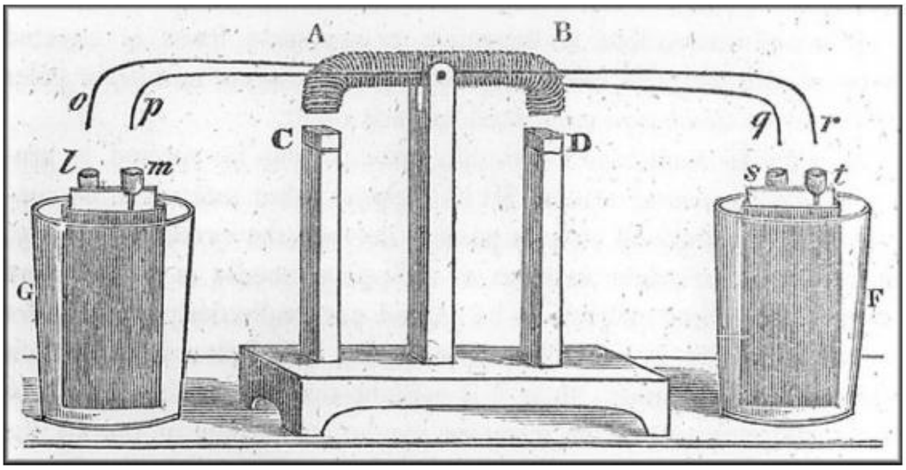


Fig 2.2 Joseph Henry's motor

2.1.3 William Sturgeon motor

Just a year after Henry's motor was demonstrated, William Sturgeon invented the commutator, and with it the first rotary electric motor. In many ways, a rotary analogue of Henry's oscillating motor. Sturgeon's motor, while still simple, was the first to provide continuous rotary motion and contained essentially all the elements of a modern DC motor

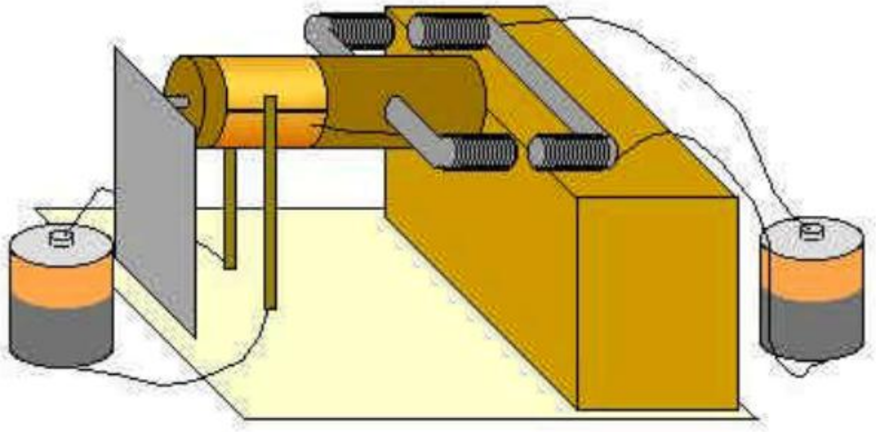


Fig 2.3 William Sturgeon motor

Because of the work of these people, DC machines are one of the most commonly used machines for electromechanical energy conversion. Converters which are used continuously to convert electrical input to mechanical output or vice versa are called electric machines..

DC machines may also work as brakes. The brake mode is a generator action but with the electrical power either regenerated or dissipated within the machine system, thus developing a mechanical braking effect. It also converts some electrical or mechanical energy to heat, but this is undesired.

2.2 Principal of operation

In any electric motor, operation is based on simple electromagnetism. A current- carrying conductor generates a magnetic field; when this is then placed in an external magnetic field, it will experience a force proportional to the current in the conductor, and to the strength of the external magnetic field. As you are well aware of from playing with magnets as a kid, opposite (North and South) polarities attract, while like polarities (North and North, South and South) repel. The internal configuration of a DC motor is designed to harness the magnetic interaction between a current- carrying conductor and an external magnetic field to generate rotational motion.

Let's start by looking at a simple 2-pole DC electric motor (here red represents a magnet or winding with a "North" polarization, while green represents a magnet or winding with a South" polarization).

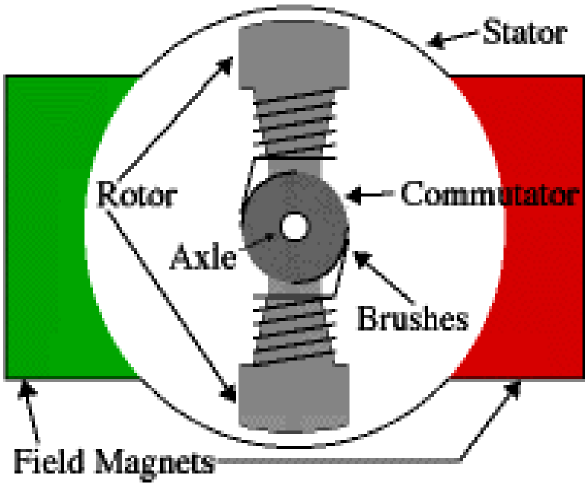


Fig 2.4 Shows two -pole DC electric motor

When power is applied, the polarities of the energized winding and the rotator magnet(s) are misaligned, and the rotor will rotate until it is almost aligned with the rotator's field magnets. As the rotor reaches alignment, the brushes move to the next commutator contacts, and energize the next winding. Given our example two-pole motor, the rotation reverses the direction of current through the rotor winding, leading to a "flip" of the rotor's magnetic field, driving it to continue rotating[38].

2.3 The construction of DC machines

The physical structure of the machine consists of two parts: the stator or stationary part and the rotor or rotating part. The stationary part of the machine consists of the frame, which provides physical support, and the pole pieces, which project inward and provide a path for the magnetic flux in the machine. The ends of the pole pieces that are near the rotor spread out over the rotor surface to distribute its flux evenly over the rotor surface. These ends are called the pole shoes. the exposed surface of a pole shoe is called a pole face, and the distance between the pole face and the rotor is called the air gap.

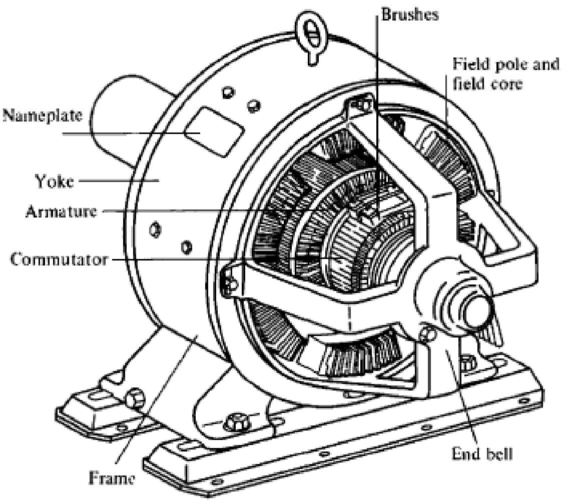


Fig 2.5 Shows construction detail of DC Motor

There are two principal windings on a dc machine: these are armature windings and the field windings. The armature windings are defined as the windings in which a voltage is induced, and the field windings are defined as the windings that produce the main magnetic flux in the machine. In a normal dc machine, the armature windings are located on the rotor, and the field windings are located on the stator. Because the armature windings are located on the rotor, a dc machine's rotor itself is sometimes called an armature [7].

2.3.1: Pole and Frame Construction

The main poles of older dc machines were often made of a single cast piece of metal, with the field windings wrapped around it. They often had bolted-on laminated tips to reduce core losses in the pole faces. Since solid-state drive packages have become common, the main poles of newer machines are made entirely of laminated material. This is true because there is a much higher ac content in the power supplied to dc Pole and Frame Construction. The main poles of older dc machines were often made of a single cast piece of metal, with the field windings wrapped around it. They often had bolted-on laminated tips to reduce core losses in the pole faces. Since solid-state drive packages have become common, the main poles of newer machines are made entirely of laminated material. This is true because there is a much higher ac content in the power supplied to dc motors driven by solid-state drive packages, resulting in much higher eddy current losses in the stators of the machines. The pole faces are typically either chamfered or eccentric in construction, meaning that the outer tips of a pole face are spaced slightly further from the rotor's surface than the canter of the pole face. [7]

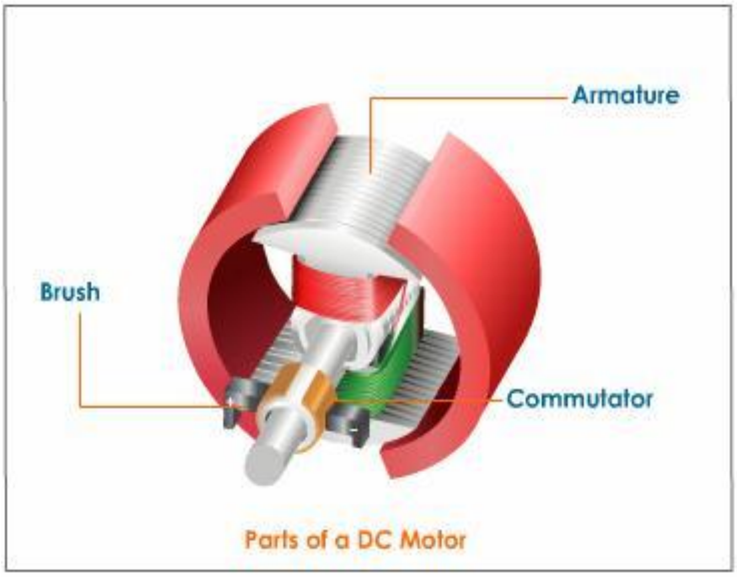


Fig 2.6 Shows Parts of DC motor

2.3.2: Commutator and Brushes

The commutator in a dc machine is typically made of copper bars insulated by a mica-type material. The copper bars are made sufficiently thick to permit normal wear over the lifetime of the motor. The mica insulation between segments is harder than the commutator material itself, so as a machine ages, it is often necessary to undercut the commutator insulation to ensure that it does not stick up above the level of the copper bars. The brushes of the machine are made of carbon, graphite, metal graphite, or a mixture of carbon and graphite. They have a high conductivity to reduce electrical losses and a low coefficient of friction to reduce excessive wear. They are deliberately made of much softer material than that of the commutator segments, so that the commutator surface will experience very little wear. The choice of brush hardness is a compromise: If the brushes are too soft, they will have to be replaced too often but if they are too hard, the commutator surface will wear excessively over the life of the machine[7]

2.4 Types of D.C. Motors

There are basically two categorization of DC Motor. One is based on their circuitry and other is based on their features & characteristics.

2.5 Types of D.C Motor Based on Circuitry

There are three basic types of dc motors: (1) shunt motors, (2) Series motors, and (3) compound motors. They differ largely in the method in which their field and armature coils are connected.

2.5.1 Shunt-wound motor

In Shunt-wound motor 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 windings are designed to produce the necessary m.m.f. so in shunt motor large number of turns of wire having high resistance is used. As a result, shunt field current is relatively small compared with the armature current.

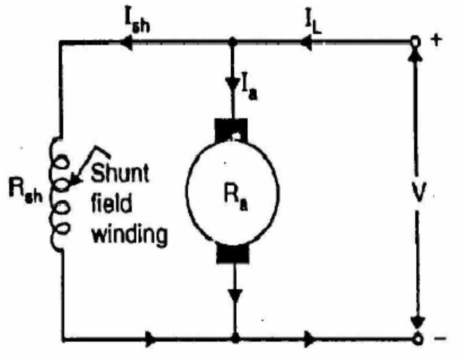


Fig 2.7 Shunt wound motor

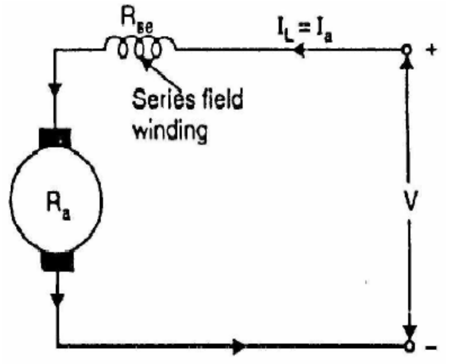


Fig 2.8 series wound motor

2.5.2: Series-wound motor

In Series-wound motor the field winding is connected in series with the armature. Therefore, series field winding carries the armature current. Since the current passing through a series field winding is come out once the same as the armature current, series field windings must be designed with small number of turns than shunt field windings 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.

2.5.3 Compound-wound motor

Compound-wound motor has two field windings; one winding is connected in parallel with the armature and the other winding in series with it. There are two types of compound motor connections. When the shunt field winding is directly connected across the armature terminals. it is called short-shunt connection. When the shunt winding shunts the series combination of armature and series field, it is called long-shunt connection. The compound machines are always designed so that the flux produced by shunt field winding is considerably larger than the flux produced by the series field winding [23].

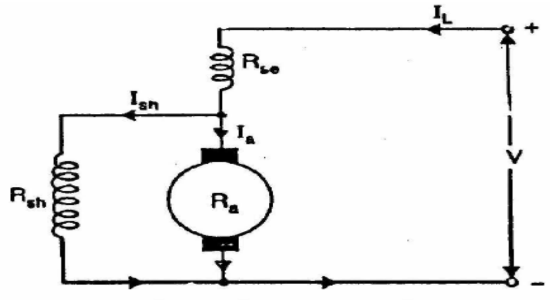


Fig. 2.9 short-shunt connection

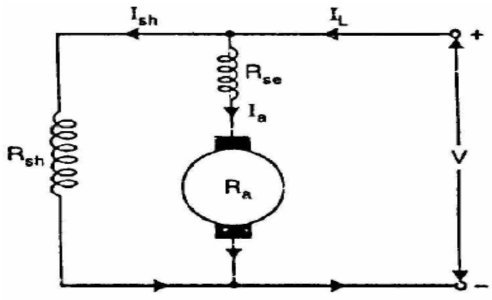


Fig.2.10 long -shunt connection

2.6 Comparison of Three Types of Motors

The characteristics of series, shunt and compound motor is shown below

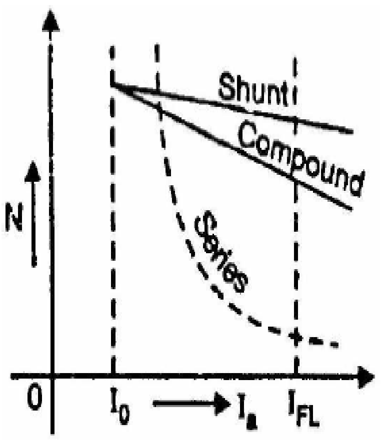


Fig.2.11 Speed and current Characteristics

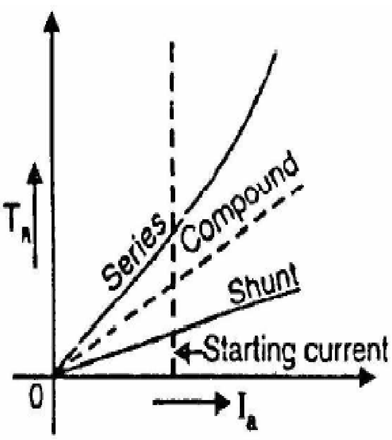


Fig.2.12 Torque and current characteristics

- The speed regulation of a shunt motor is better than that of a series motor. But, speed regulation of a cumulative compound motor lies between shunt and series motors.
- For a given armature current, the starting torque of a series motor is more than that of a shunt motor. But, the starting torque of a cumulative compound motor lies between series and shunt motors.
- Both shunt and cumulative compound motors have definite no-load speed. But, a series motor has dangerously high speed at no-load.

2.7 Applications

2.7.1 Applications of Shunt motors

The characteristics of a shunt motor describes that it is an approximately constant speed motor. It is, therefore, used

(i) Where the speed is required to remain almost constant from no-load to full-load

(ii) Where the load has 10 be driven at a number of speeds and any one of which is required to remain nearly constant

2.7.2 Industrial use of DC shunt motor

Lathes, drills, boring mills, shapers, spinning and weaving, machines etc.

2.7.3 Applications of Series motors

It is a variable speed motor i.e., speed is low at high torque and vice-versa. However, at light or no-load, the motor tends to attain dangerously high speed. The motor has a high starting torque. It is, therefore, used

(i) Where large starting torque is needed e.g., in elevators and electric traction of D.C Motors.

(ii) Where the load is subjected to large fluctuations and the speed is automatically required to reduce at high torques and vice-versa.

2.7.4 Industrial use of DC Series motor

Electric traction, cranes, elevators, air compressors, vacuum cleaners, hair drier, sewing machines etc.

2.7.5 Application of Compound motors

Differential-compound motors are rarely used because of their poor torque characteristics. However, cumulative-compound motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

2.7.6: Industrial use of compound motor

Presses, shears, reciprocating machines etc.

2.8 Types of DC motor Based on Characteristics

DC Motors differ from AC Motors, as they are powered by a direct current of Electricity, as an Alternating current. There are three main types of Direct Current motor, each with different features and characteristics. These are:

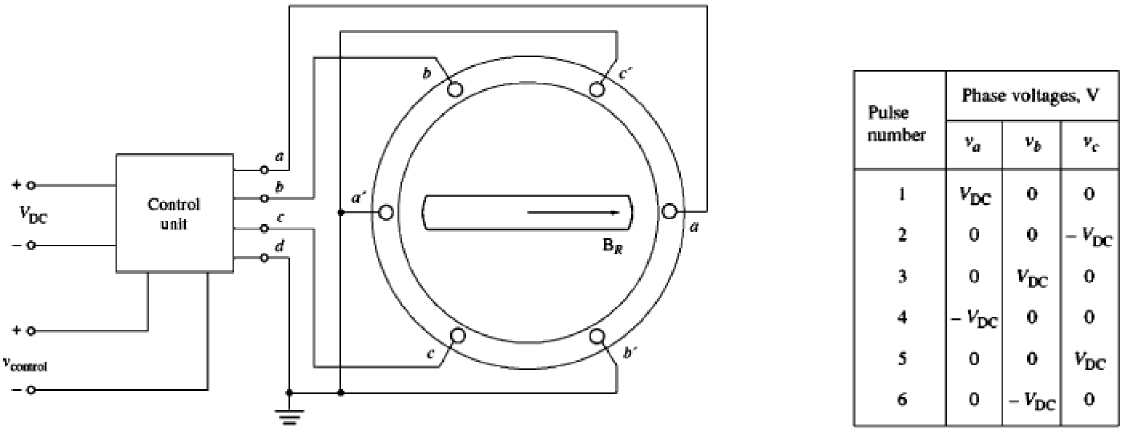
2.8.1 Stepper DC Motors

A stepper motor can move in accurate angular increments knows as steps in response to the application of digital pulses to an electric drive circuit from a digital controller. The number and rate of the pulses control the position and speed of the motor shaft. Generally, stepper motors are manufactured with steps per revolution of 12, 24, 72, 144, 180, and 200, resulting in shaft increments of 30, 15, 5, 2.5, 2, and 1.8 degrees per step.

If a dc voltage is applied to phase *a* of the stator and no voltage is applied to phases band c, then a torque will be induced in the rotor which causes it to line up with the stator magnetic field Bs. Now assume that phase *a* is turned off and that a negative dc voltage is applied to phase c. The new stator magnetic field is rotated 60° with respect to the previous magnetic field, and the rotor of the motor follows it around. By continuing this pattern, it is possible to construct a table showing the rotor position as a function of the voltage applied to the stator of the motor. If the voltage produced by the control unit changes with each input pulse in the order shown in Table , then the stepper motor will advance by 60° with each input pulse. It is easy to build a stepper motor with finer step size by increasing the number of poles on the motor. The number of mechanical degrees moved per step decreases with increasing numbers of poles. For example, if the stepper motor has eight poles, then the mechanical angle of the motor's shaft will change by 15° per step. The speed of a stepper motor can be related to the number of pulses into its control unit per unit time by using Equation of Θ_m .

$$\Theta_m = \frac{2}{P}\Theta_e$$

Where Θ_m is mechanical angle and Θ_e is electrical angle. Equation gives mechanical angle of a stepper motor as a function of the electrical angle.



Pulse number	Phase voltages, V		
	v_a	v_b	v_c
1	V_{DC}	0	0
2	0	0	$-V_{DC}$
3	0	V_{DC}	0
4	$-V_{DC}$	0	0
5	0	0	V_{DC}
6	0	$-V_{DC}$	0

Fig 2.13 Shows Stepper motor

If both sides of this equation are differentiated with respect to time, then we have a relationship between the electrical and mechanical rotational speeds of the motor [7].

2.8.2 Brushless DC Motors

Conventional dc motors have traditionally been used in applications where dc power sources are available, such as on aircraft and automobiles. However, small de motors of these types have a number of disadvantages. The principal disadvantage is excessive sparking and brush wear. Small, fast dc motors are too small to use compensating windings and inter poles, so armature reaction and *L di/dt* effects tend to produce sparking on their commutator brushes. In addition, the high rotational speed of these motors causes increased brush wear and requires regular maintenance every few thousand hours. I f the motors must work in a low-pressure environment (such as at high altitudes in an aircraft), brush wear can be so bad that the brushes require replacement after less than an hour of operation. Such motors have been developed in the last 25 years by combining a small motor much like a permanent magnetic stepper motor with a rotor position sensor and a solid-state electronic switching circuit. These motors are called brushless motor because they run from a dc power source but do not have commutators and brushes. The rotor is similar to that of a permanent magnet stepper motor, except that it is non salient. The stator can have three or more phases [7].

The basic components of a brushless dc motor are

1. A permanent magnet rotor
2. A stator with a three, four, or more phase winding
3. A rotor position sensor
4. An electronic circuit 10 control the phases of the rotor winding

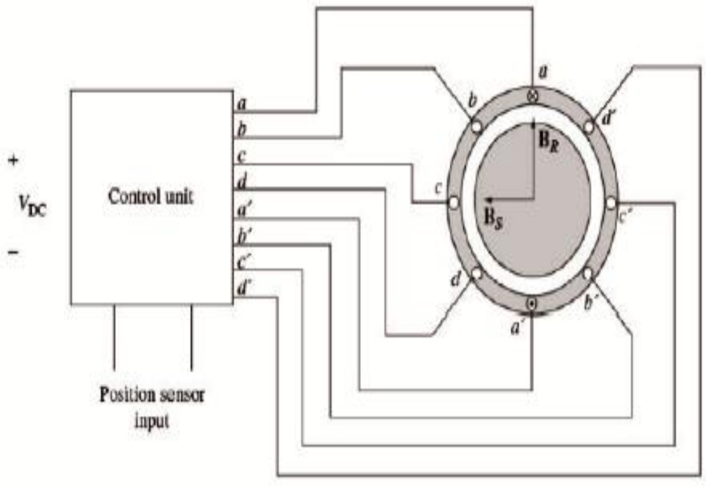


Fig 2.14 Shows Brushless DC motor

2.8.3 Brushed DC Motors

Brushed DC motors are the classic DC motors, which include a split ring commutator, and can be powered by any kind of DC battery. These motors are often considered to be limited, due to the need that brushes will always be in contact with the commutator ring, hence creating friction. Brushes also scratch the surface of the ring, which eventually will lead to replacement of the brushes and ring. Although the brushes in these motors were originally made from copper wire , they are now made from carbon, which is a longer-lasting material, gives less friction, and is cheaper The advantages of Brushed DC motors are that their initial cost is extremely low, and that they have an extremely simple speed control system.

2.9 Constraints in D.C. Motors

Several troubles may arise in a d.c. motor and a few of them are discussed below:

- Failure to start
- Sparking in DC Motor
- Vibrations and pounding noises
- Overheating

2.10: DC Motors Selection

The following factors require consideration while selection of DC motor.

Speed Range

If we are using field control and a large speed range is required, the base speed must be lower and the motor size must be larger.

Speed Variation with Torque

Applications requiring constant speed at all torque demands should use a shunt-wound dc motor. If we want to minimize speed change with load, a dc motor regulator, must be used.

Reversing

If the dc motor cannot be stopped for switching before reverse operation. Then, compound and stabilizing dc motor windings should not be used, and a suitable armature-voltage control system should supply power to the dc motor. Motor size needed may be determined by either the heating or peak torque requirement.

Peak Torque

Therefore, the dc motor's peak torque depends on the duration and frequency of occurrence of the overload. Dc motor peak torque is often limited by the maximum current that the power supply can deliver.

Heating

The best method to predict a given dc motor's operating temperature is to use thermal capability curves available from the dc motor manufacturer. If curves are not available, dc motor temperature can be estimated by the power-loss method. This method requires total losses versus load curve or an efficiency curve.

2.11 Position control

Most of the existing linear controllers generally cannot lead to good tracking and regulation responses when the controlled system has a wide range of operating conditions. The nonlinear effects caused by a motor frequently reduce stability, which reduces the controller's ability to maintain position at set points. Hence number of the industrial process applications requires position control of DC motor. The position control of Dc motor can be done by open loop control or close loop control.

2.11.1 Open loop position control

In general open loop control means that you send electrical signal to an actuator to perform a certain action, like connecting a motor to a battery .in this scheme of control, there is no any mean for your controller to make sure the task was performed correctly, and it often need human intervention to obtain accurate result. A very simple example of open loop control, is the remote controller of an RC toy car, you the human have to constantly check the position and the velocity of the car to adapt to situation and move the car to the desired place.

2.11.2 Close loop position control

In open loop control all of the tasks performed by a human in an open, while obtaining more accurate result with extremely short response time? Then we use closed loop control. In order to be able to build a closed loop controller, you need some mean of gaining information about the rotation of the shaft like the number of revolutions executed per second, or even the precise angle of the shaft. This source of information about the shaft of the motor is called "feedback" because it sends back information from the controller actuator to the controller.

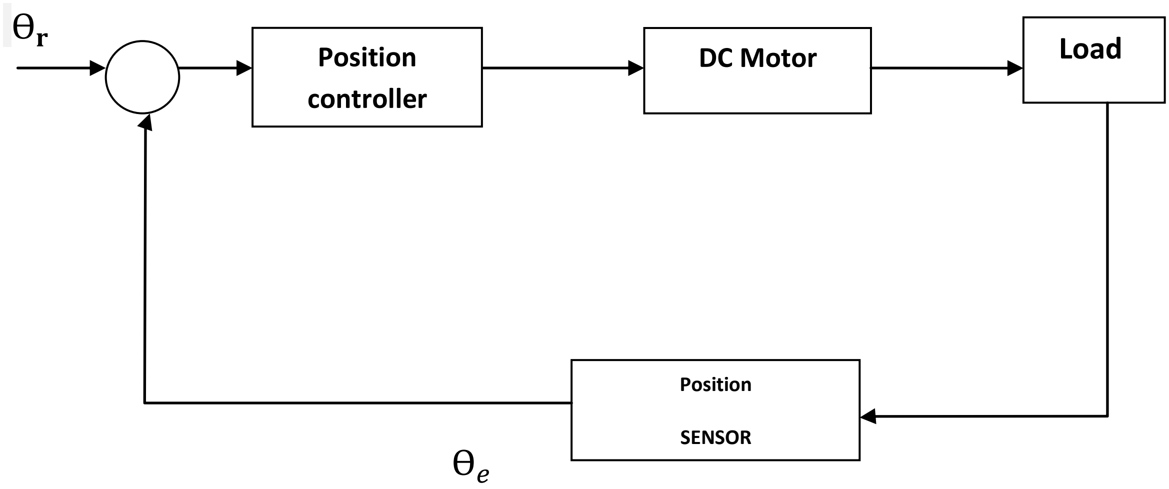


Fig 2.15 Block diagram of close loop position control

In other words, a closed loop controller will regulate the power delivered to the motor to rech the required velocity. If the motor is to turn faster than the required velocity, the controller will deliver less power to the motor. Controlling the electrical power delivered to the motor , is usually done by Pulse Width Modulation [37].

2.11.3 Shaft encorder

when workig with DC motor, a shaft encorder is the most common and accurate way of providing feed back to the controller. Shaft encorder come in many shapes and sizes, but they all rely of the same principle. In encorder a U shapped photo couple made of Infra Red sender and matching receviver is positioned in a certain way so that he beam of infrared light passes through one of the small openinig in the encorder disk. Any photo couple has four leads, two leads for the sender, which is usually an infra Red LED and the Two other are for the receiver, which is usually a photo transistor.

Fig 2.16 Shows classic encorder disk

The encorder disk is firmly connected to the back shaft of the motor, so that both the shaft and the encorder disk rotate at the same r.p.m. the back shaft is an etension of the output shaft of the motor at its back, usually present for the sole purpose of adding a shaft encorder. When the encorder disk is inseted in the configuration the rotation of the motor causes the beam of liight to be periodically intercepted by the solid parts of the encorder disk creating a Sequence of pulses of light, that will be translated by the photo couple's receiver into pulses of electercity.Those pulses of electricity contain all the information we need to implement a closed loop control. The frequency of those pulses is directly propotionnal to the speed of the rotor of the shaft(RPM) and the number of those pulses correspond to the angular displacement of the shaft. The more the number of holes in an encorder disk, the higer will be the reslution that is the slightest angular displacement that can be detected[37]

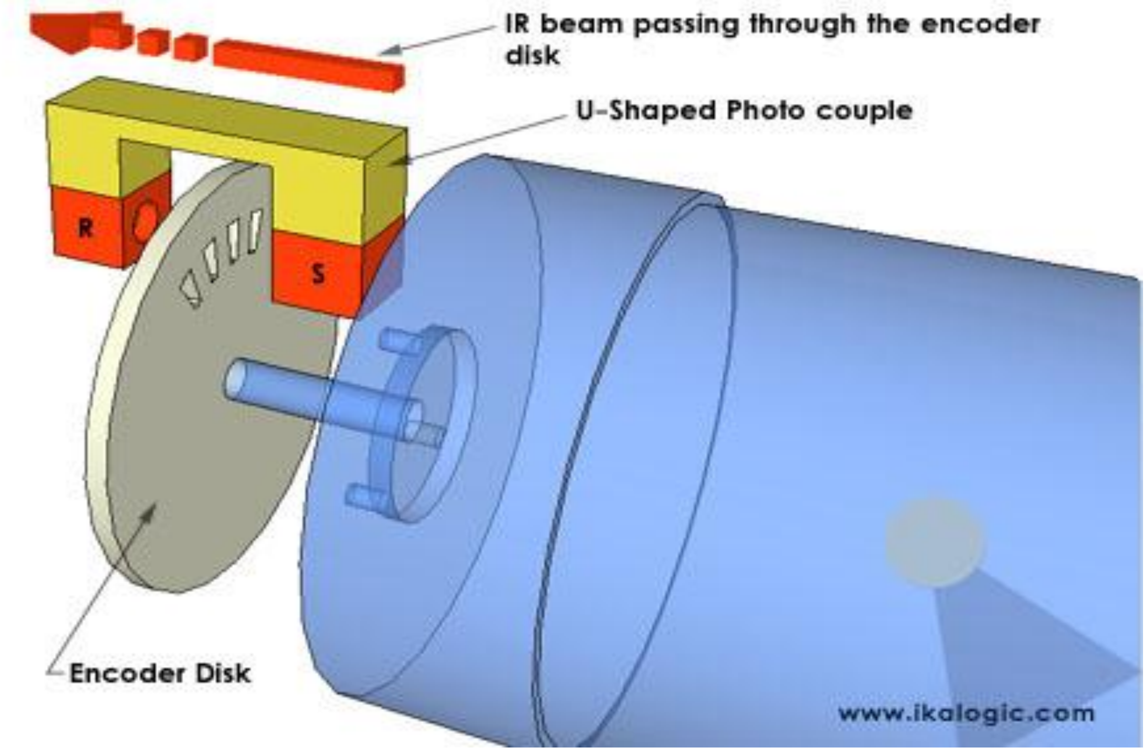


Fig 2.17 Shows Shaft encorder

CHAPTER 3 Fuzzy Logic

3.1 Introduction

The concept of Fuzzy Logic (FL) was conceived by Lotfi Zadeh, a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time[35].

Fuzzy logic has become one of the most sophisticated control system. Fuzzy logic resemble human decision making power. It has the ability to generate precise solution from certain or approximate information. In fill gap in engineering design methods that was left vacant by purely mathematical approaches and purely logic based approaches in system design. While other approaches accurate equation to model real word behaviours.

Fuzzy design can work well with ambiguities of real world behaviours. It provides an intuitive method for describing system in human term and automates the conversion of those system specifications into effective models.

3.2 What is fuzzy logic?

“Fuzzy logic is a mathematical discipline, based on fuzzy set theory, which allows for degrees of truth or falsehood”. As opposed to “binary logic” which holds that an assertion must be either true or false. ‘Fuzzy logic’ accommodates the possibility that the assertion can be partly false. The degree of truth or falsehood in the assertion can be both qualitatively and quantitatively described. As mentioned above fuzzy logic deals with uncertainty, ambiguity and imprecision, which widely exist in complex real world problems especially in engineering. Fuzzy logic is a multi-valued logic primarily concerned with the uncertainty and approximate reasoning. The intelligent soft technique mimic’s human decision making process and is biologically inspired.

3.3 Difference between classical set and fuzzy set

3.3.1 Classical set

A classical (crisp) set A in the universe of discourse U can be defined by listing all of its members (the list method) or by specifying the properties that must be satisfied by the members of the set(the rule method). The list method can be used only for finite sets and is therefore limited use. The rule method is more general. In the rule method, a set A is represented as

$$A=\{x \in U \mid x \text{ meets some conditions}\}$$

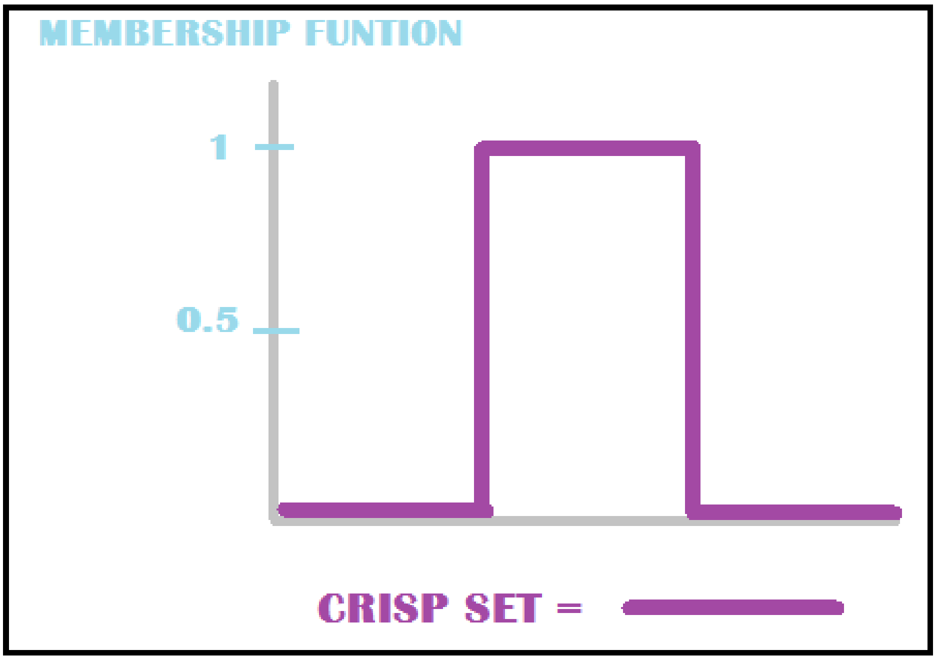


Fig 3.1 Shows Classical set

Another method to define a classical set A-the membership method, which introduces a zero-one membership function (also called characteristic function) for A, denoted by µA(x),such that

$$\mu_A(x), = \{1 \text{ if } x \in A \\ 0 \text{ if } x \text{ not} \in A\}$$

3.3.2 Fuzzy set

A fuzzy set in a universe of discourse U is characterized by a membership function µA(x) that akes values in the interval zero and one.

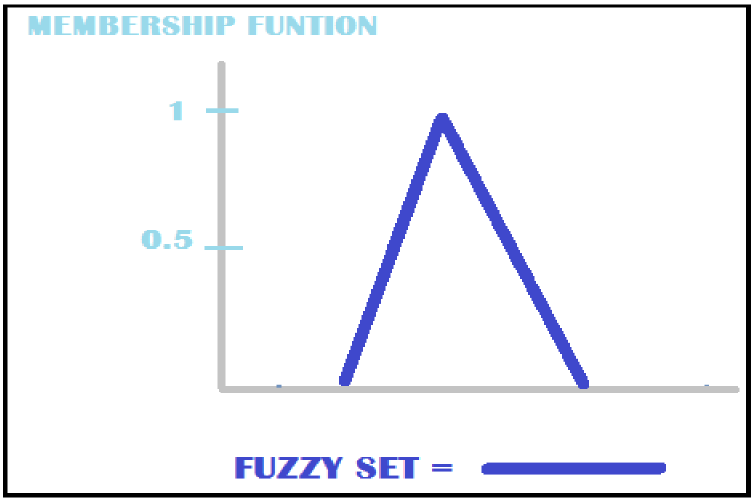


Fig 3.2 Shows Fuzzy Set

A fuzzy set A in U may be represented as a set of ordered pairs of a generic element x and its membership values, that is A fuzzy set A in U may be represented as a set of ordered pairs of a generic element x and its membership values, that is

$$A=\{(x,\mu_A(x))|x\epsilon U\}$$

Where A is Fuzzy set $\mu_A(x)$ is membership function of X, in fuzzy set A for each $x\epsilon U$.

3.4 Mathematical operation on fuzzy sets

With the basic notation and designation for fuzzy sets some fundamental operation as fuzzy sets are given below. The classical sets operations such as union, intersection and compliment are applicable to fuzzy set theory as well, which are often referred as t-operator, t-conform and negation. let us assume A and B two fuzzy sets defined in some universe of discourse(UOD). The various Mathematical operations on fuzzy sets A and B are as follows:

3.4.1 Union

The union of two fuzzy sets A and B is the smallest fuzzy set which include all articles in A or B or A and B. The union is a logical OR operator written as A+B or A U B, where MF is defined

$$\mu_{A+B}(x) = \text{Max}\,[\mu_A(x), \mu_B(x)]$$

3.4.2 Intersection

Then intersection of two fuzzy sets A and B is the largest fuzzy set within both A and B. The intersection is a logical AND operator written A∩B or A. B, where MF is defined as

$$\mu_{A.B}(x) = \text{Min}\,[\mu_A(x), \mu_B(x)]$$

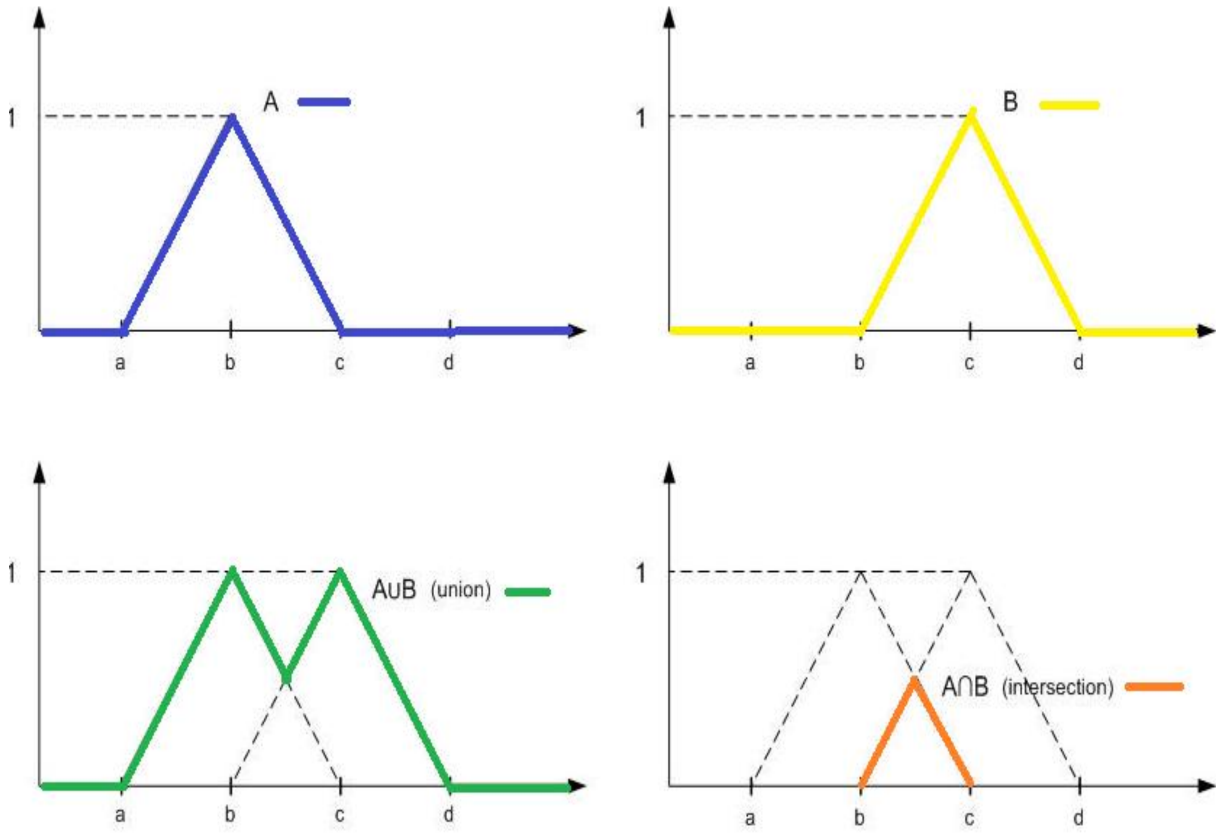


Fig 3.3 Shows Union and Intersection

3.4.3 Compliment (negation)

The compliment of fuzzy set A is defined as

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x),$$

Complement of A = {x|**x** is not near an integer}

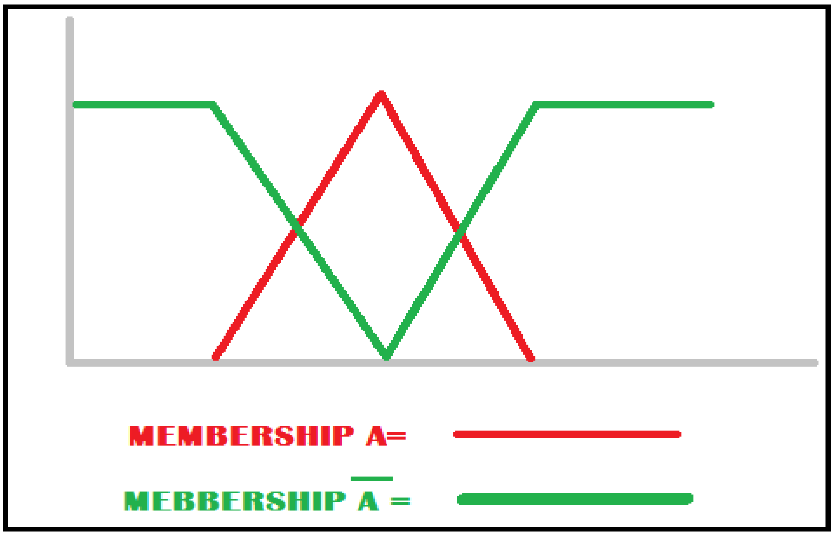


Fig no 3.4 Shows Compliment of A

3.4.4 Subset

Fuzzy set A is contained in fuzzy set B (or equivalently A is subset of B, or A is similar than or equal to B) if and only if

$$\mu_A(\mathbf{x}) \le \mu_B(\mathbf{x}) \quad \text{for all x.}$$

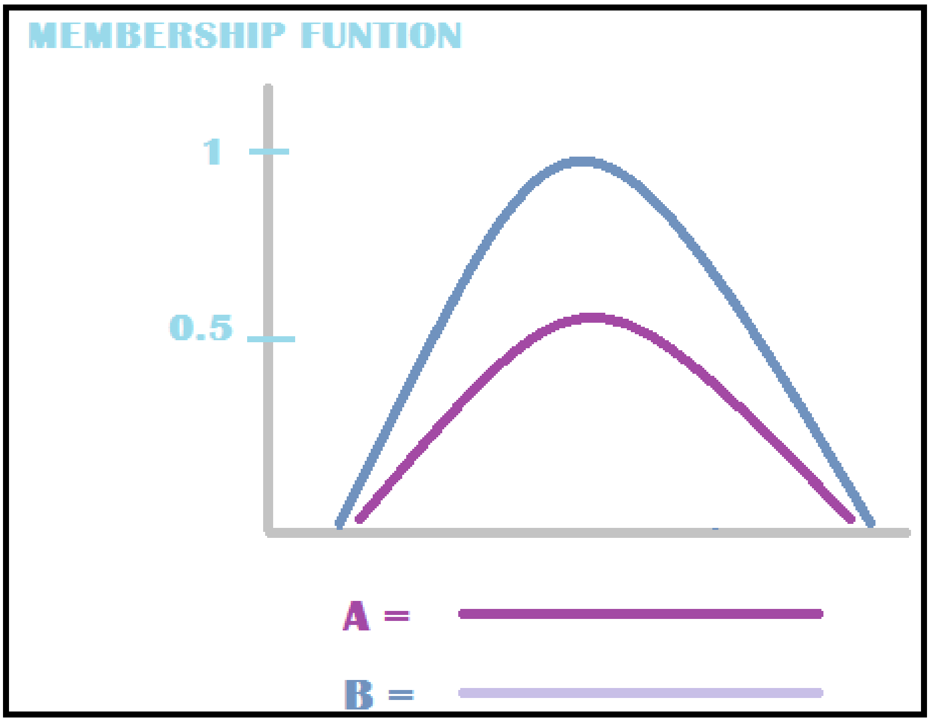


Fig 3.5 Shows Fuzzy subset

3.4.5 Double negation law (involution):

$$\overline{\overline{A}} = A, \overline{\overline{B}}\text{=B}$$

3.5 Basic terminology in fuzzy logic

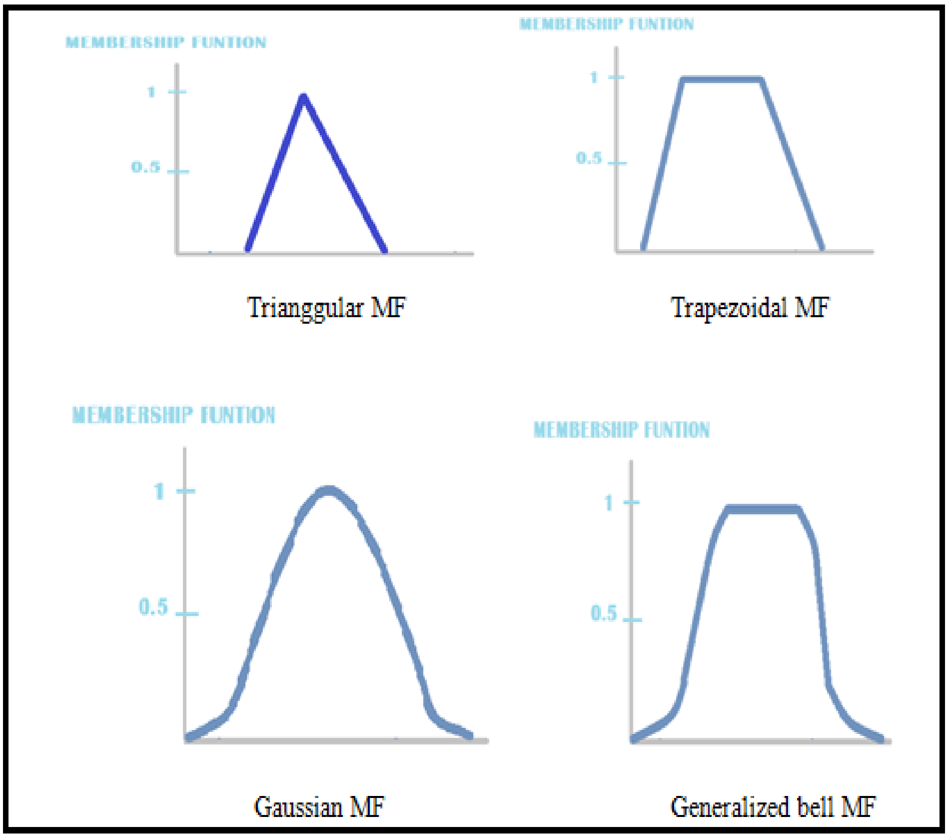
The basic terminologies in fuzzy logic are

3.5.1 Degree of membership (μ)

The degree of membership is the degree to which a crisp variable belongs to a fuzzy set. It is expressed either as a fractional value ranging from 0.0 to 1.0 or percentage ranging from 0% to 100%.

3.5.2 Membership Function

A membership function (MF) is normally expressed graphically and tends to illustrate how completely a crisp variable belongs to a fuzzy set.



Trianggular MF

Trapezoidal MF

Gaussian MF

Generalized bell MF

Fig no 3.6 Membership funtion type

In order to define fuzzy membership function, designers choose many different shapes based on their preference and experience. There are generally four types of membership functions used:

1: Trapezoidal MF 2: Triangular MF

3: Gaussian MF 4: Generalized bell MF

Among them the most popular shapes are triangular and trapezoidal because these shapes are easy to represent designer‟s idea and require low computation time.

3.5.3 Crisp variable

A crisp variable is a physical variable that can be measured through instruments and can be assigned a crisp value, such as a temperature of 250°C, an output voltage of 5.35 V etc.

3.5.4 Linguistic variable

If a variable can take words in natural languages as its values, it is called a linguistic variable, where the words are characterized by fuzzy sets defined in universe of discourse in which the variable is defined. Roughly speaking, if a variable can take words in natural languages as its values, it is called a linguistic variable.

3.6 Ranking

With ranking we can compare fuzzy subsets and we can arrange them in a certain order. Especially in decision making situations, appropriate methods are needed to compare and evaluate different alternatives. we cannot explicitly say that a fuzzy number A is larger than another fuzzy number B as in the numerical case. Whether A is larger, smaller or equal to B is a matter interpretation. A simple method for ordering fuzzy subsets consists in the definition of a ranking function F, mapping each fuzzy set to the real numbers, where a natural order exists. [17, 27]

3.7 Fuzzy rules

Human beings make decisions based on rules. Although, we may not be aware of it, whatever decisions are made are all based on computer if then statement. For example if weather is fine, then we may decide to go out. If the forecast says weather will be bad today, but fine tomorrow, then we make a decision not to go today, and we will go tomorrow. Fuzzy machines, which always tend to mimic human behaviour and try to work in the same way. However, the decision and the means of choosing that decision are replaced by fuzzy setsand rules are replaced by fuzzy rules. Fuzzy rules also operate using a series of if-then statements. For example, if X then A, if y then B, where A and B are all sets of X and Y. fuzzy rules define fuzzy patches, which is the key idea in fuzzy logic [12]

3.8 Fuzzy logic controller (FLC)

Fuzzy logic is widely in fuzzy logic controller and signal processing application. A fuzzy logic system maps into crisp input and crisp output. Hence there are 8 major tasks typically needed for developing fuzzy logic system.

- Define the problem
- Define the linguistic variables.
- Define behaviour of control surfaces (fuzzy rules)
- Define reasoning mechanism (fuzzy inference)
- Build the system
- Test the system.

- Tune and validate the system.

A fuzzy logic controller has four main components as shown in Figure:

a) Fuzzification

b) Inference engine

c) Fuzzy Rule base and fuzzy set database

d) Defuzzification

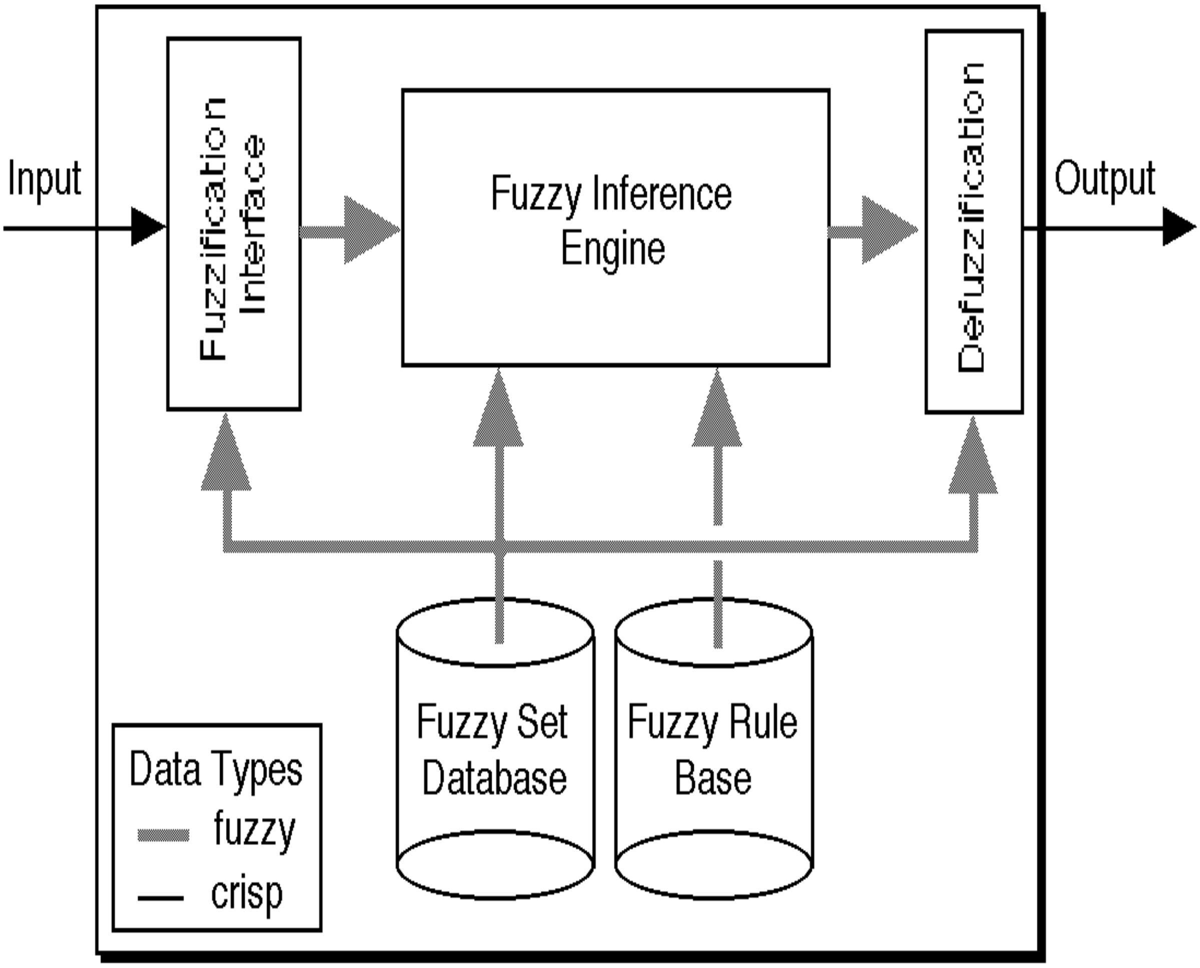


Fig 3.7 Block diagram of fuzzy logic controller

3.8.1 Fuzzification

The first step in designing a fuzzy controller is to decide which state variables represent the system dynamic performance must be taken as the input signal to the controller. Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called fuzzification. This is achieved with the different types of fuzzifiers. There are generally three types of fuzzifiers, which are used for the fuzzification process; they are

1. Singleton fuzzifier
2. Gaussian fuzzifier
3. Trapezoidal or triangular fuzzifier

3.8.2 Fuzzy Rule base

The rules are in “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error (e) and change in error (de). In a rule based controller the control strategy is stored in a more or less natural language. 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.

3.8.3 Fuzzy Inference engine

In the inference sub process, the truth value for the premise of each rule is computed and applied to the conclusion part of the rule. The result of this is assigning a fuzzy subset to each output variable of each rule. The truth value of the precondition of a rule is referred to as its strength and is denoted by α . The rule’s strength is computed by the means of equations of complement, union and intersection.

Example: Assume we have the following rule:

R: IF *x* is *A* AND *y* is *B* THEN *z* is *C*

If we have the sensor readings x_0 and y_0 ,x and y respectively, the strength of the rule R can be computed as $\alpha = \mu_A(x_0) \cap \mu_B(y_o)$

Of course, the rule’s premise may include disjunctions and negations as well as conjunctions. The premise is then computed on the basis of the previous given definitions of union, intersection and complement of fuzzy sets.

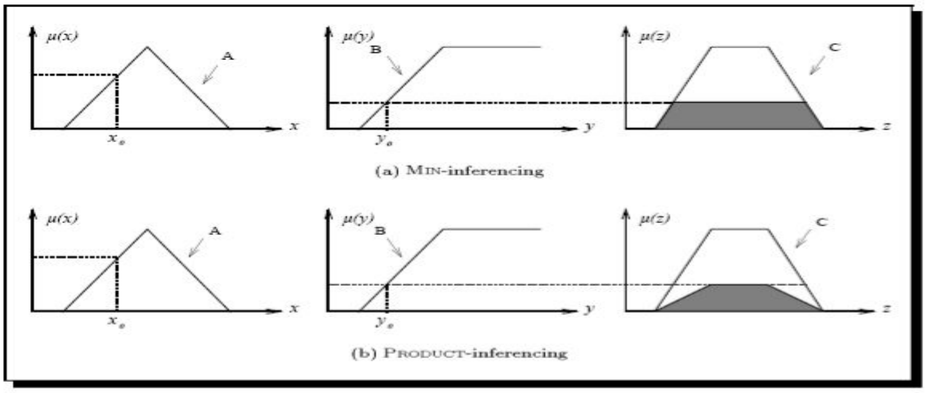


Fig 3.8Fuzzy inference engine

We also apply more complex operations than min and max for fuzzy inferencing. There are two widely used inference methods: Min-inferencing and Product-inferencing. In Miin inferencing, the output membership function is clipped off at a height corresponding to rule’s degree of truth. In Product-inferencing, the output membership function is scaled by the rule’s computed degree of truth. A graphical illustration of the two inferencing methods is shown in figure

3.8.4 Defuzzification

- The reverse of Fuzzification is called Defuzzification. The use of Fuzzy Center of gravity (COG)
- Bisector of area (BOA)
- Mean of maximum (MOM)
- Smallest of Minimum (SOM)
- Largest of Maximum (LOM)

Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number). According to real world requirements, the linguistic variables have to be transformed to crisp output. There are many defuzzification methods but the most common methods are as follows

3.9 Application area of fuzzy logic

- Fuzzy logic is conceptually easy to understand. The mathematical concepts behind fuzzy reasoning are very simple.
- Fuzzy logic is flexible. With any given system, it’s easy to massage it or layer more functionality on top of it without starting again from scratch.
- Fuzzy logic is tolerant of imprecise data.
- Fuzzy logic can be built on top of the experience of experts. In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you rely on the experience of people who already understand your system.
- Fuzzy logic can be blended with conventional control techniques.
- Fuzzy logic is based on natural language. The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic.

3.10 Practical Applications of Fuzzy Logic

- Image processing
- Communication engineering
- Production engineering
- Consumer electronics
- System identification

CHAPTER 4 Self Tuned Fuzzy PID Controller

4.1 PID controller

PID is made up of three main components:

P – Proportional control. The output varies based on how far we are from our target.
I – Integral control. The output varies based on how long it’s taking to get to target.
D – Derivative control. The output varies based on the change in the error. Greater change is greater response, good for dampening spikes and jumps.

The controller takes a measured value from a process or other apparatus and compares it with a reference setpoint value. The difference (or "error" signal) is then used to adjust some input to the process in order to bring the process' measured value back to its desired setpoint. Unlike simpler controllers, the PID can adjust process outputs based on the history and rate of change of the error signal, which gives more accurate and stable control.

PID controllers do not require advanced mathematics to design and can be easily adjusted (or "tuned") to the desired application, unlike more complicated control algorithms based on optimal control theory. PID controller‘s algorithm are mostly used in feedback loops. PID controllers can be implemented in many forms. It can be implemented as a stand-alone controller or as part of Direct Digital Control (DDC) package or even Distributed Control System (DCS). The later is a hierarchical distributed process control system which is widely used in process plants such as iron and steel or oil refining industries.

It is interesting to note that more than half of the industrial controllers in use today utilize PID or modified PID control schemes. Below is a simple diagram illustrating the schematic of the PID controller. Such set up is known as non interacting form or parallel form The PID controller calculation involves three separate parameters, the proportional, the integral and derivative values, denoted P, I, and D. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element. Heuristically, 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. By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the setpoint and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

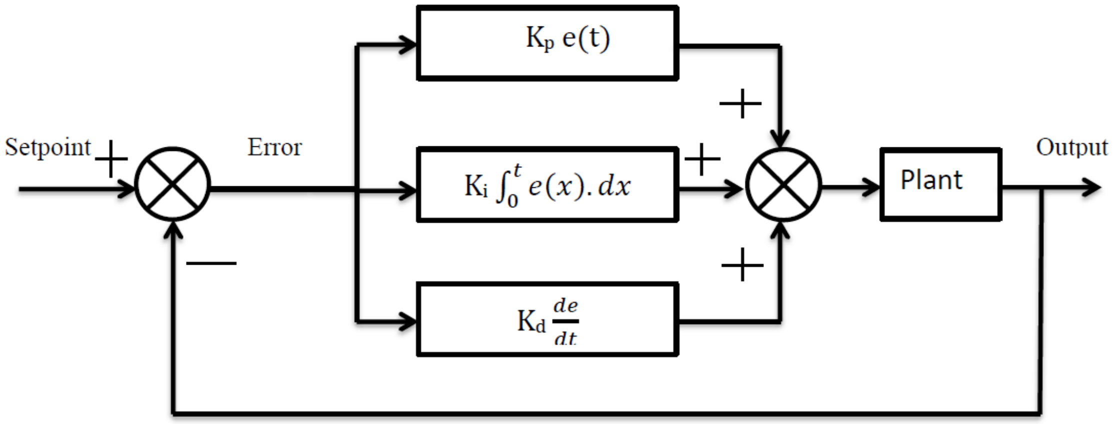


Fig 4.1 : Block diagram of PID controller

4.1.1 Proportional control

It has a varying output based on the error between current position and target position. It also has a “gain” value. This is essentially a sensitivity control; the higher this number is the more responsive the output is to the error.

The formula for P is:

$$P_{OUT} = K_P * K_{ERR}$$

The formula for K_{ERR} is:

$$K_{ERR} = \text{Target Point} - \text{Current Point}$$

P_{OUT} is the result, K_P is the gain and the K_{ERR} is the error. As we can see it’s simply a multiplication of the error multiplied by gain. The higher the gain, the more response we get per unit of error. It suffers from a problem called “Steady State Error” and makes it unsuitable for most applications by itself.

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive or sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. In the absence of disturbances, pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain.

An example of this is using P controller is that when we turn to a certain gyro heading on a robot. As we approach the target heading, motor power output goes down and eventually there's so little power, it stalls, and is stuck perpetually stalled short of its goal. It's still trying to move, but there just isn't enough power. Usually this is where Integral control is introduced to finish the job.

4.1.2: Integral control

Integral (I) Control is similar to P control; however instead of the current error, it uses the integrated error. That is the sum of the error every cycle around. The longer it takes you to reach your target, the higher the integrated error becomes and the higher the output. This is most useful in completing a P based control. Using the above example of a turn, when the power level output by P control became low enough to stall, the integrated error starts to build up and keep the robot turning, as it approaches the target the P error continues to drop, and generally the I output will cause an overshoot and then drive it back.

The formula for I control is:

$$\text{IOUT} = \text{KI} * \text{IERR}$$

The formula for IERR is:

$$\text{IERR} = \text{Previous IERR} + \text{KERR}$$

By using both you will almost certainly reach your target, once your gains are properly "tuned" to the proper values. Tuning is a fairly simple procedure, but it takes time. Most of the time the best you can get is for it to overshoot the target slightly and back towards it.

4.1.3 Derivative Control

Derivative control, D, sometimes called Delta control because it's actually driven by the change, or delta, of the KERR. As such it can be used to react to sudden changes in error, and is good for maintaining a certain position or velocity on a closed loop system. The formula for D is:

$$D_{out} = D_{ERR} * K_D$$

The formula for DERR is:

$$D_{ERR} = K_{ERR} - \text{Previous } K_{ERR}$$

derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller setpoint. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

4.1.4: Full PID control

Full PID control is simply the combination of the results of all three formulas. Different combinations of the formulas are good for different situations. For example, PI is good at getting you to a spot quickly, but is not the most accurate; PD can reach a spot fairly quickly and hold it fairly well. PID can accurately maintain a position, but is not the fastest or gentlest.

4.1.5 Ziegler-Nichols method

In the 1940's, Ziegler and Nichols devised two empirical methods for obtaining controller parameters. Their methods were used for non-first order plus dead time situations, and involved intense manual calculations. With improved optimization software, most manual methods such as these are no longer used. However, even with computer aids, the following two methods are still employed today, and are considered among the most common.

The Ziegler-Nichols closed-loop tuning method allows us to use the ultimate gain value, K_u, and the ultimate period of oscillation, P_u, to calculate K_c . It is a simple method of tuning PID controllers and can be refined to give better approximations of the controller. We can obtain the controller constants K_c , T_i , and T_d in a system with feedback. The Ziegler-Nichols closed-loop tuning method is limited to tuning processes that cannot run in an open-loop environment.

Determining the ultimate gain value, K_u, is accomplished by finding the value of the proportional-only gain that causes the control loop to oscillate indefinitely at steady state. This means that the gains from the I and D controller are set to zero so that the influence of P can be determined. It tests the robustness of the K_c value so that it is optimized for the controller. Another important value associated with this proportional-only control tuning method is the ultimate period (P_u). The ultimate period is the time required to complete one full oscillation while the system is at steady state. These two parameters, K_u and P_u, are used to find the loop-tuning constants of the controller (P, PI, or PID). To find the values of these parameters, and to calculate the tuning constants, use the following procedure:

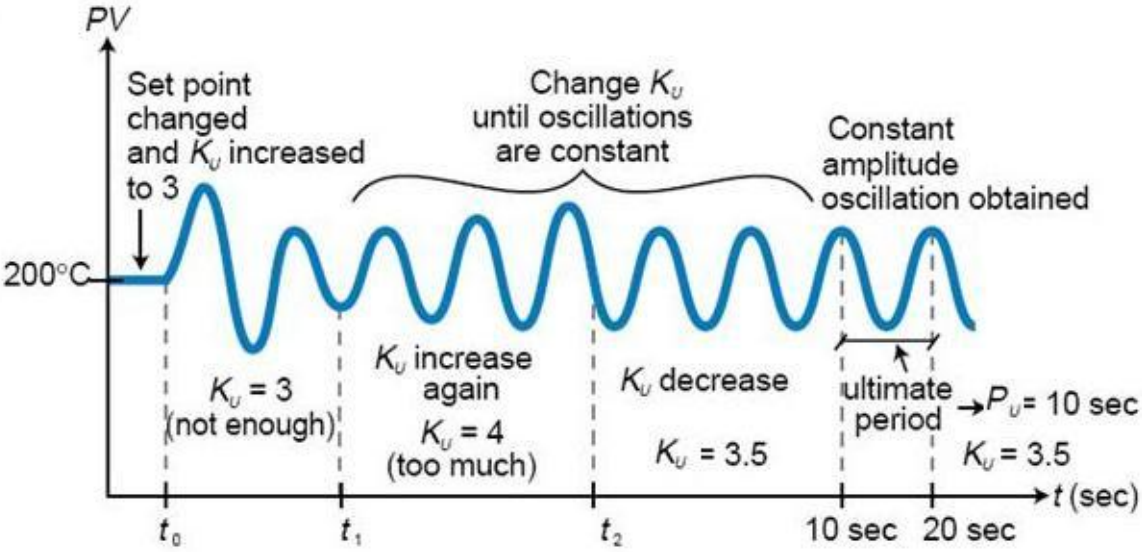


Fig 4.2 Ziegler-Nichols closed-loop tuning method

1. Remove integral and derivative action. Set integral time (T_i) to 99999 or its largest value and set the derivative controller (T_d) to zero.
2. Create a small disturbance in the loop by changing the set point. Adjust the proportional, increasing and/or decreasing, the gain until the oscillations have constant amplitude.
3. Record the gain value (K_u) and period of oscillation (P_u).

Plug these values into the Ziegler-Nichols closed loop equations and determine the necessary settings for the controller.

4.1.5 Advantages

1. It is very easy only need to change the P controller.

2. It includes dynamics of whole process, which gives a more accurate result of how the system is behaving.

4.1.6 Disadvantages

1. But some time experiment is time consuming.
2. Sometime it can venture into unstable regions while testing the P controller, which could result the system to become out of control.

Table no. 4.1: Zigler-Nichols Closed loop method

	K_c	T_I	T_D
P	$\frac{K_v}{2}$		
PI	$\frac{K_v}{2.2}$	$\frac{P_U}{1.2}$	
PID	$\frac{K_v}{1.7}$	$\frac{P_U}{2}$	$\frac{P_v}{8}$

4.2 Self tuned Fuzzy PID Controller

PID control requirements model structure which is precise, and in practical applications, to different extent, most of industrial processes exist to the nonlinear model, thus by using conventional PID controller it is not possible to achieve precise control of the process. But the problem with fuzzy controller is that its dependence on the mathematical model is week. So it isn't possible to establish the precise mathematical model of the process, but the fuzzy control has a good robustness and adaptability. According to their own characteristics, we combine fuzzy control with PID control, and provide a based on fuzzy PID parameters self-tuning controller with MATLAB [30].

A fuzzy PID controller takes the conventional PID controller as the foundation which uses the fuzzy reasoning and variable universe of discourse to regulate the PID parameters. The chracteristics of a fuzzy system such as robustness and adaptabilty can be successfully incorporated into the controlling method for better tuning of PID parameters.

In self-tuning the characteristics of the controller to tune its controlling parameters on-line automatically so by self tuning the most suitable values of those parameters .which result in optimization of the process output. Fuzzy self-tuning PID controller works on the control rules designed on the basis of theoretical and experience analysis. Fuzzy control tune the parameters Kp, Ki, and Kd by adjusting the other controlling parameters and factors on-line.

This result as the precision of overall control higher and hence gives a better performance than the conventional PID controller or a simple fuzzy PID controller without self-tuning ability.

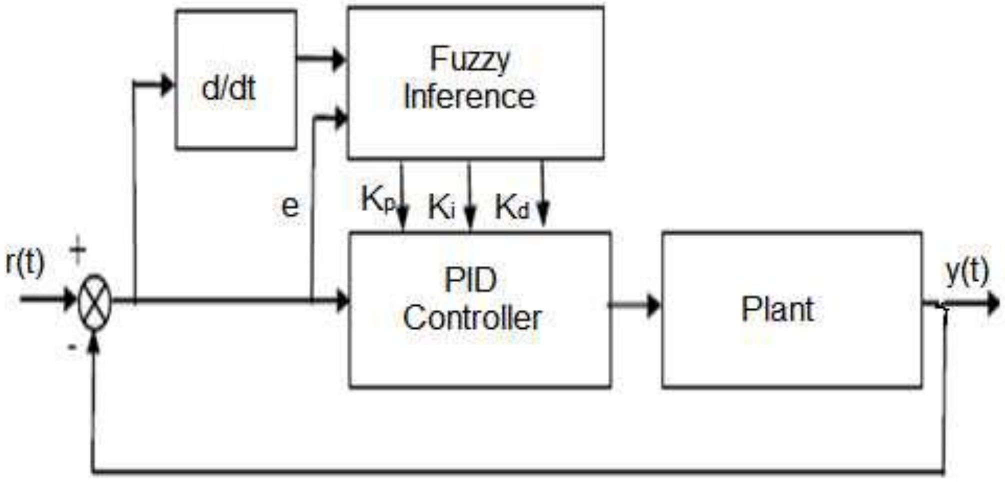


Fig 4.3 Block diagram of Self-tuned PID Controller

In order to get the desired output performance of FLC, the rules and membership functions are changed. The membership functions are adjusted by making the area of membership functions near ZE region narrower to produce finer control resolution. On the other hand, making the area far from ZE region wider gives faster control response. Also the performance can be improved by changing the severity of rules. Adaptive corrections can be made by the following methods,

$$Kp = kp + \Delta Kp$$
$$Ki = ki + \Delta Ki$$
$$Kd = kd + \Delta Kd$$

Here Kp’, Ki’, and Kd’ refer to the previous value of the PID parameters whereas kp, ki, and kd refer to the new corrected values of the parameters after a particular tuning step was completed.

4.2.2: Design of Fuzzy Rules when we use only one controller.

Rule bases for tuning K_P

Table 4.2 Rule bases for tuning KP

CE E	NL	NM	NS	ZE	PS	PM	PB
NL	PL	PL	PM	PM	PS	ZE	ZE
NM	PL	PL	PM	PS	PS	ZE	NS
NS	PM	PM	PM	PS	ZE	NS	NS
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NM	NM	NL
PM	PS	ZO	NS	NM	NM	NM	NL
PL	ZE	ZE	NM	NM	NM	NL	NL

Rule bases for tuning K_I

Table 4.3 Rule bases for tuning Ki

CE E	NL	NM	NS	ZE	PS	PM	PB
NL	NL	NL	NM	NM	NS	ZE	ZE
NM	NB	NL	NM	NS	NS	ZE	ZE
NS	NB	NM	NS	NS	ZE	PS	PS
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PS	PM	PM
PM	ZE	ZE	PS	PM	PM	PB	PB
PL	ZE	ZE	PS	PM	PM	PL	PL

Rule bases for tuning K_D

Table 4.4 Rule bases for tuning KD

E \ CE	NL	NM	NS	ZE	PS	PM	PB
NL	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZE
NS	ZE	NS	NM	NM	NS	NS	ZE
ZE	ZE	NS	NS	NS	NS	NS	ZE
PS	ZE	ZE	NS	NS	NS	NS	ZE
PM	PL	NS	PS	PS	PS	PS	PL
PL	PL	PM	PM	PM	PS	NS	PL

4.2.2 Advantages of fuzzy self-tuning PID controller

The followings are the advantages of fuzzy self-tuning PID controller over the conventional PID controller :

1) While operating the traditional PID controller cannot able to change it’s parameters Kp, Ki and Kd.
2) But we can tune PID controller by using fuzzy inference while operating.
3) In self-tuning PID controller the decisions can be made through fuzzy reasoning rules according to the size, the direction and the changing tendency of the system error together with the dynamic changing of process characteristics.
4) The uncertainty of model are very high, thus by using conventional PID control the precise control of the process cannot be achieved.
5) If we only use fuzzy control its dependence mathematical model is weak, but it has good robustness and adaptability, we can made the precise mathematical model with robustness and adaptability. so we combine PID and Fuzzy.

6) The simulation results shows that: , fuzzy self-tuning PID controller has a better dynamic response curve, shorter response time, small overshoot, high steady precision, good static and dynamic performance as compared with the traditional PID controllers.

4.3 Two Controllers control

It is not possible to design a single controller which acts as fast and precisely with small as well big error. So it is better to use two controllers one for small error and other for big error.

There are two fuzzy PID controllers, with using scaling factor and if-then rule, one acts for reducing the big error (first fuzzy PID controller) and the other acts for attenuating small error(second fuzzy PID controller).

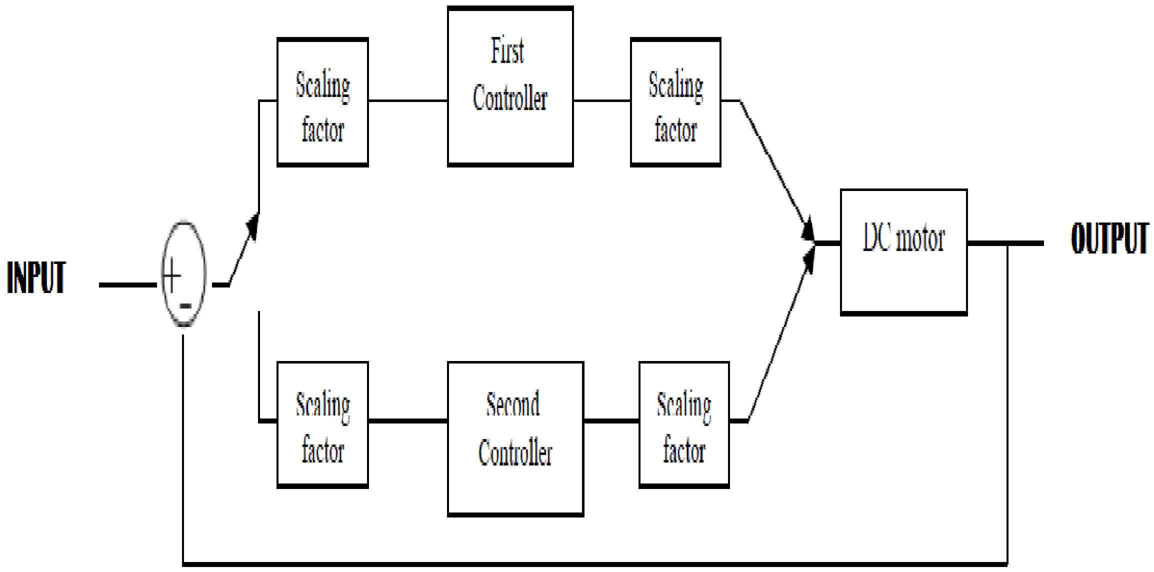


Fig 4.4 Block diagram of Two controller system

The error is difference between actual and desired rotor position angle. The load and parameter Disturbance can cause the switching between controllers. If system parameter changes during time or in present of disturbance, The controller will be switched automatically and acts as an adaptive controller.

For example if we set the value 20 degree when error is more than 20, second controller will work but as soon as error became less than 20 degree first controller take control. This controller overcome uncertainly and reduces the error. It shows better performance in compare with classic controllers. As the fuzzy systems are a non linear mapping method using the nonlinear model is easy to control the system without linearization or any other simplification in system describing equations [15].

4.3.1 Design of Fuzzy Rules for first controller

Rule bases for tuning K_P for first controller

Table 4.4 Rule bases for tuning K_P for first controller

E \ CE	NL	NS	ZE	PS	PL
NL	**PVL**	**PVL**	**PVL**	**PVL**	**PVL**
NS	**PML**	**PML**	**PML**	**PL**	**PVL**
ZE	**PVS**	**PVS**	**PS**	**PMS**	**PMS**
PS	**PML**	**PML**	**PML**	**PL**	**PVL**
PL	**PVL**	**PVL**	**PVL**	**PVL**	**PVL**

Rule bases for tuning K_I for first controller

Table no 4.5 Rule bases for tuning K_I for first controller

E \ CE	NL	NS	ZE	PS	PL
NL	**PM**	**PM**	**PM**	**PM**	**PM**
NS	**PMS**	**PMS**	**PMS**	**PMS**	**PMS**
ZE	**PS**	**PS**	**PVS**	**PS**	**PS**
PS	**PMS**	**PMS**	**PMS**	**PMS**	**PMS**
PL	**PM**	**PM**	**PM**	**PM**	**PM**

Rule bases for tuning K_D for first controller

Table no 4.7 Rule bases for tuning K_D for first controller

CE E	NL	NS	ZE	PS	PL
NL	**PVS**	**PMS**	**PM**	**PL**	**PVL**
NS	**PMS**	**PML**	**PL**	**PVL**	**PVL**
ZE	**PM**	**PL**	**PL**	**PVL**	**PVL**
PS	**PML**	**PVS**	**PVL**	**PVL**	**PVL**
PL	**PML**	**PVL**	**PVL**	**PVL**	**PVL**

4.3.2 Design of Fuzzy Rules for second controller.

Rule bases for tuning K_P for second controller

Table no 4.8 Rule bases for tuning Kp for second controller

CE E	NL	NS	ZE	PS	PL
NL	**PVL**	**PVL**	**PVL**	**PVL**	**PVL**
NS	**PML**	**PML**	**PL**	**PL**	**PVL**
ZE	**PVS**	**PVS**	**PS**	**PMS**	**PMS**
PS	**PML**	**PML**	**PML**	**PL**	**PL**
PL	**PVL**	**PVL**	**PVL**	**PVL**	**PVL**

Rule bases for tuning K_I for second controller.

Table 4.9 Rule bases for tuning KI for second controller.

CE E	NL	NS	ZE	PS	PL
NL	**PM**	**PM**	**PM**	**PM**	**PM**
NS	**PM**	**PMS**	**PMS**	**PMS**	**PMS**
ZE	**PS**	**PS**	**PVS**	**PS**	**PS**
PS	**PMS**	**PMS**	**PMS**	**PMS**	**PMS**
PL	**PMS**	**PM**	**PM**	**PM**	**PM**

Rule bases for tuning KD for second controller.

Table 4.10 Rule bases for tuning KD for second controller

CE E	NL	NS	ZE	PS	PL
NL	**PVS**	**PMS**	**PM**	**PL**	**PVL**
NS	**PMS**	**PML**	**PL**	**PVL**	**PVL**
ZE	**PM**	**PL**	**PL**	**PL**	**PVL**
PS	**PML**	**PVS**	**PVS**	**PVL**	**PVL**
PL	**PML**	**PVL**	**PVL**	**PVL**	**PVL**

CHAPTER 5 Modelling and Simulation

5.1 Modelling a DC Motor

To be modelling a DC Motor, simple circuit of its electrical diagram as shown in is considered. To be Modelling and Simulate the DC motor, the following steps are to be made step by step

Step1: Represent the DC motor circuit diagram.
Step2: Represent system equations
Step3: Convert to model block
Step4: Run the Simulation

5.2 Closed-Loop System Consideration

To perform the simulation of the system, an appropriate model needs to be established. Therefore, a model based on the motor specifications needs to be obtained. Fig. 4.1 shows the DC motor circuit with Torque and Rotor Angle consideration.

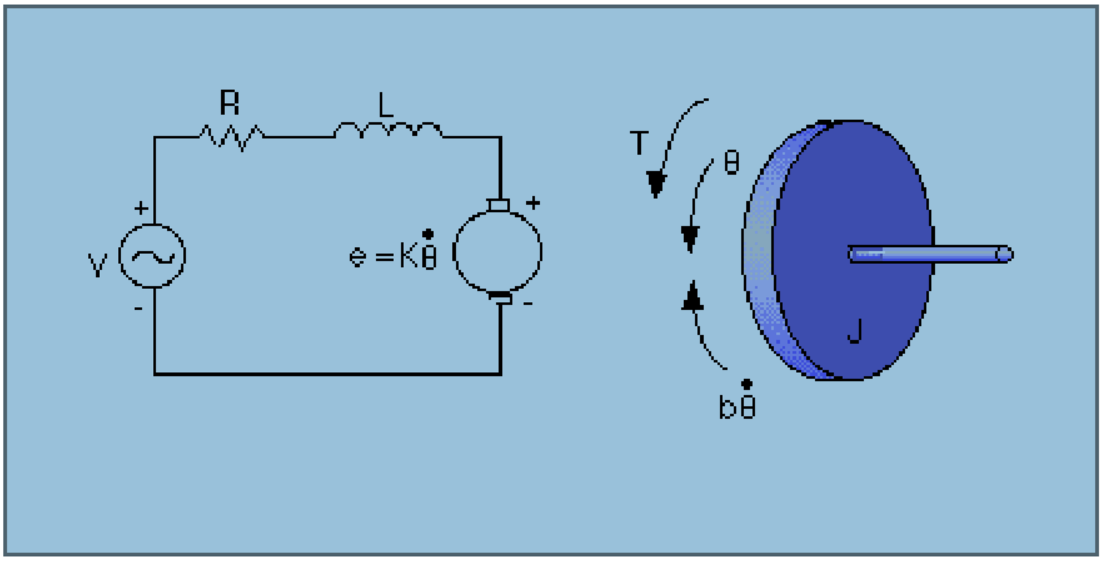


Fig 5.1 Schematic diagram of a DC motor

5.3 System Equations

The motor torque **T** is related to the armature current, **i** , by a torque constant **K**;

$T = K i$ .... (1)

The generated voltage, **e_a**, is relative to angular velocity by;

$e_a = K\, w_m = K\, d\theta/dt$.. (2)

From Fig. 4.1 we can write the following equations based on the Newton's law combined with the Kirchhoff's law:

$J\, d2\theta/dt2 + b\, d\theta/dt = K\, i$ ....(3)

$L\, di/dt + Ri = V - K\, d\theta/dt$ ....(4)

5.4 Transfer Function

Using the Laplace transform, equations (3) and (4) can be written as:

$J\, s2\, \theta(s) + b\, s\, \theta(s) = K\, I(s)$.. (5)

$L\, s\, I(s) + R\, I(s) = V(s) - K\, s\, \theta(s)$ ....(6)

Where *s* denotes the Laplace operator. From (6) we can express I(*s*):

$$I(s) = \frac{V((S)-Ks\Theta(s))}{R+LS}\ldots\ldots(7)$$

And substitute it in (5)

$$Js^2\Theta(s) + bs\Theta(s) = \frac{K(V(s)-KS\Theta(s))}{R+Ls}\ldots\ldots(8)$$

This equation for the DC motor is shown in the block diagram in Fig. 4.2. From equation (8), the transfer function from the input voltage, **V** (*s*), to the output angle, θ, directly follows:

$$G(s) = \frac{\Theta(s)}{V(s)} = \frac{K}{[S\{(R+Ls)(JS+b)+K^{2}\}]}\ldots\ldots (9)$$

* moment of inertia of the rotor (J) = 1.5000e-004 kg.m^2/s^2

* damping ratio of the mechanical system (b) = 1.0000e-003 Nms

* electromotive force constant (K=Ke=Kt) = 1.0 Nm/Amp

* electric resistance (R) = 2 ohm

- electric inductance (L) = 0.0052 H
- input (V): Source Voltage
- output (theta): position of shaft
- The rotor and shaft are assumed to be rigid

5.5: Simulation of DC motor

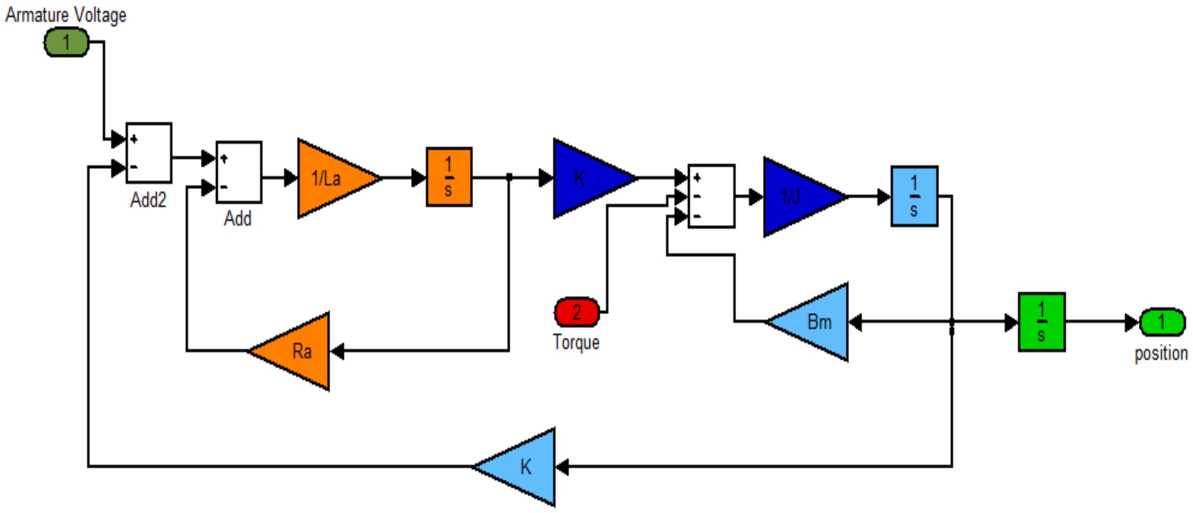
Newton's law and Kirchoff's law applied to the motor system give the following equations:

$$J\frac{d^2t}{dt^2} = T - b\,\frac{d\theta}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

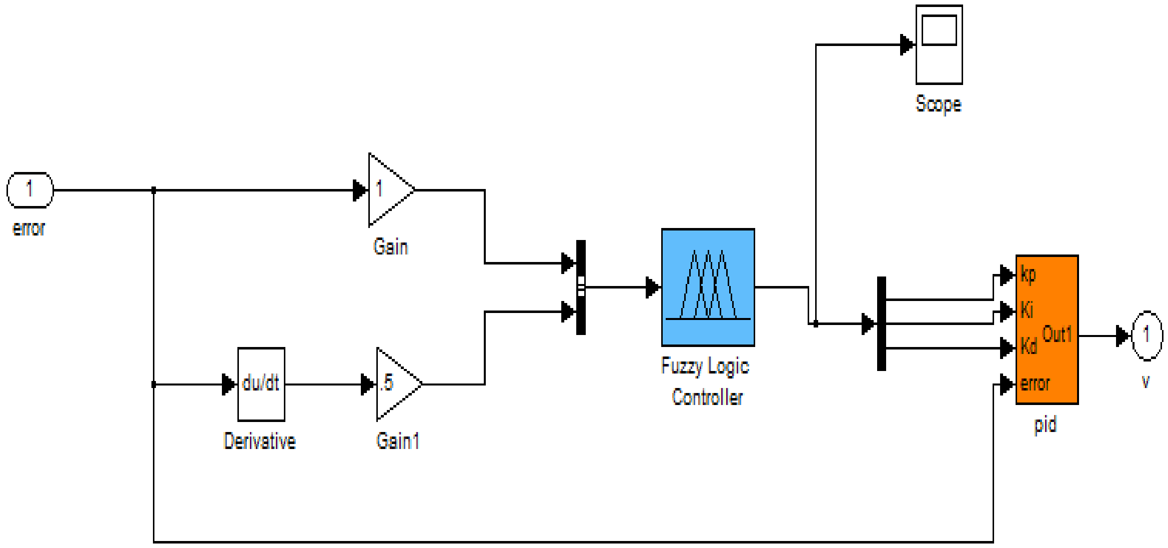
$$\frac{d^2t}{dt^2} = \frac{1}{J}\left(K_t\, i - b\,\frac{d\theta}{dt}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

$$L\,\frac{di}{dt} = -\,Ri + V - e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

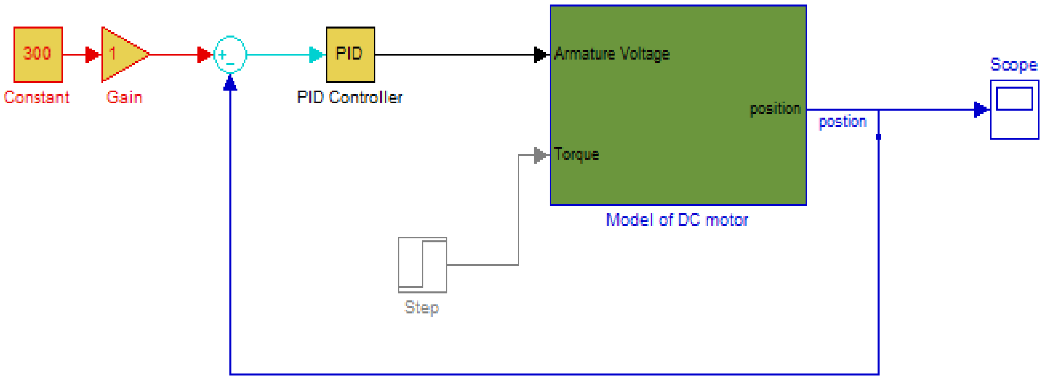
$$\frac{di}{dt} = \frac{1}{L}\left(-Ri + V - Ke\frac{d\theta}{dt}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$



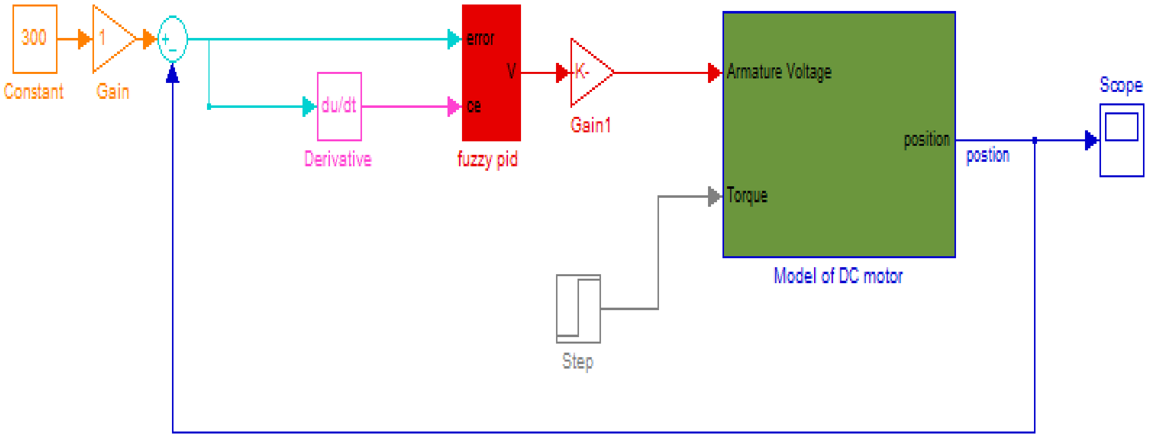
5.6 Simulation of Self Tuned Fuzzy PID controller.



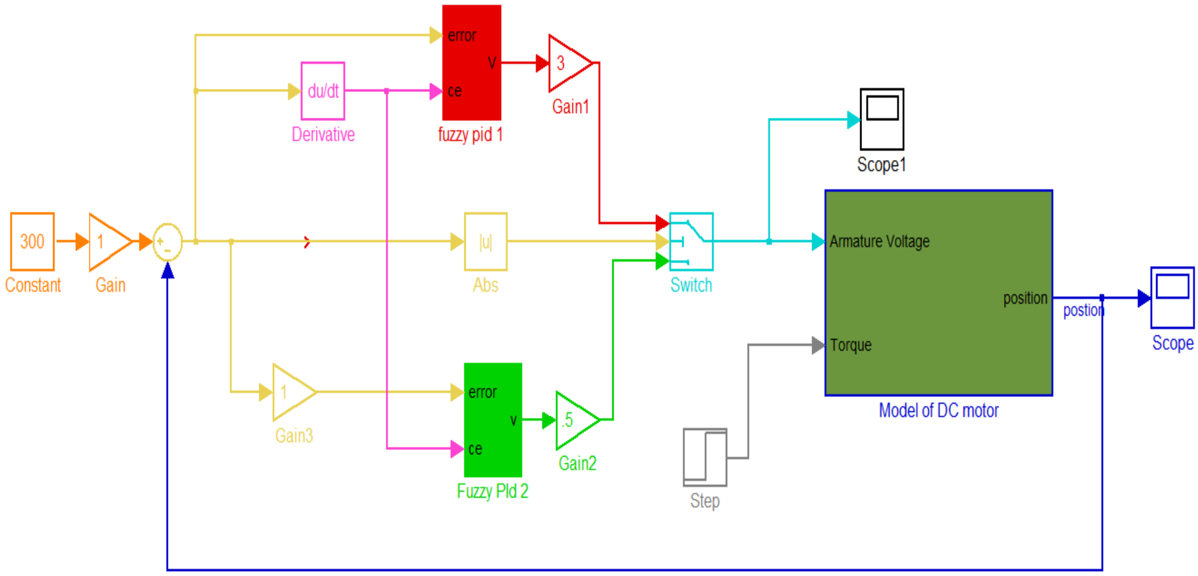
5.7 Simulation of DC Motor Position Control by PID controller.



5.8 Simulation of DC Motor Position Control by Self tuned Fuzzy PID controller.

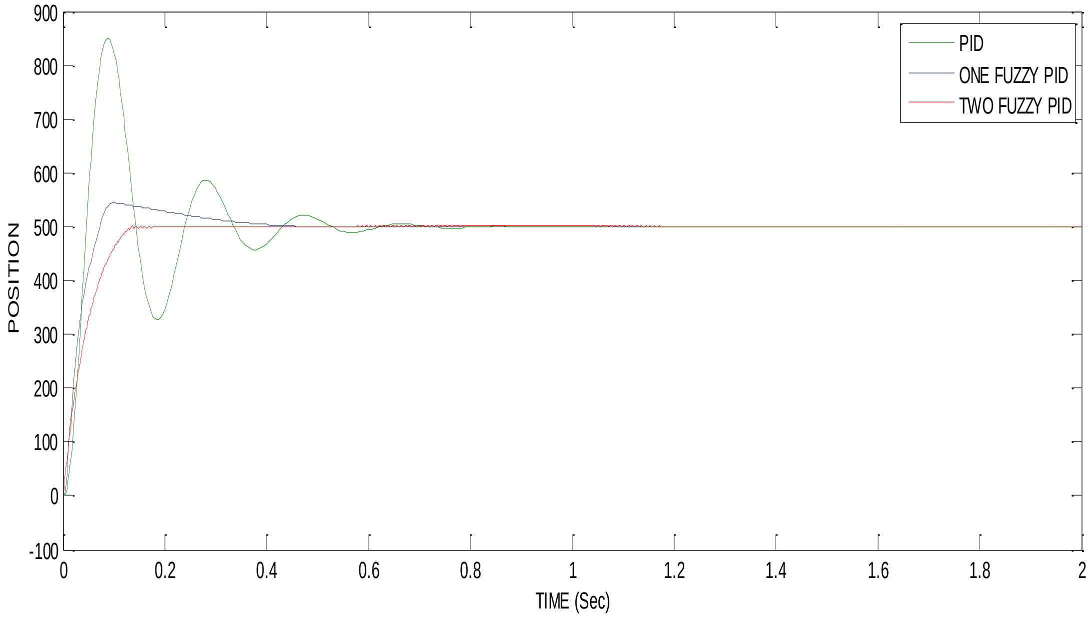


5.9 Simulation of DC Motor Position Control by use of Two Self Tuned Fuzzy PID controller.

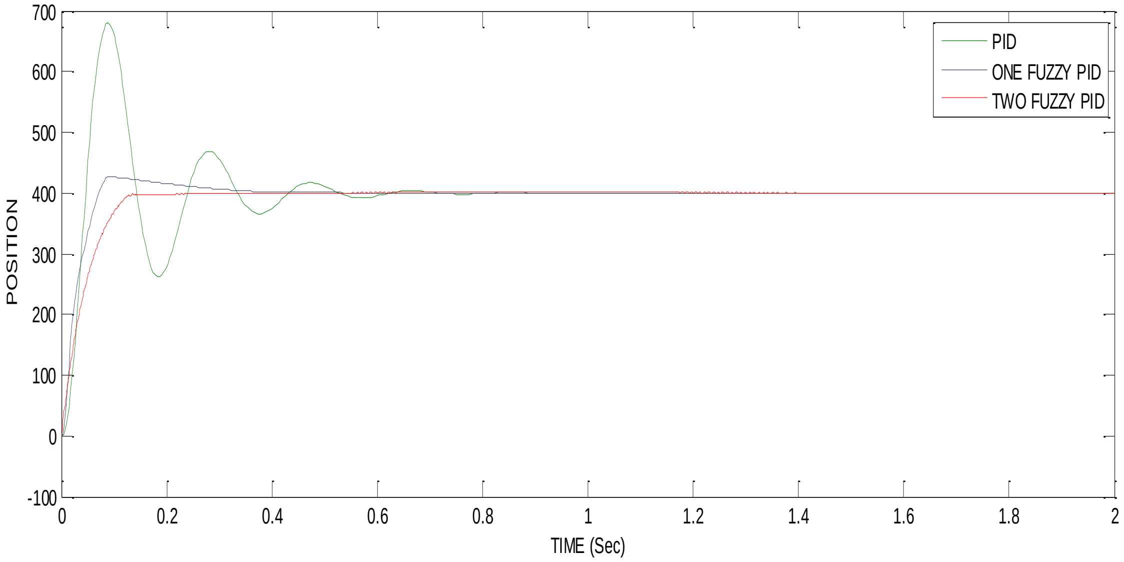


CHAPTER 6 Results, comparison and Conclusion

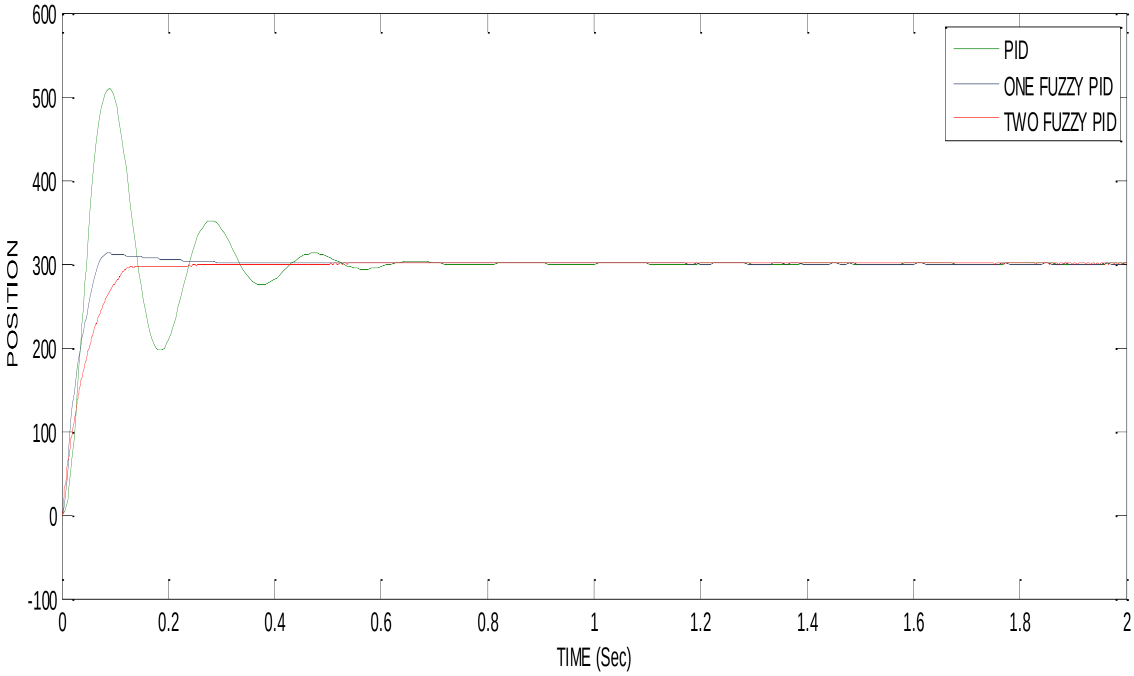
6.1 Results when refrence position is 500 degree.



6.2 Results when reference position is 400 degree



6.3 Results when ref position in 300 degree.



6.4 Comparison between Rise time, Max percentage overshoot and Settling time of PID, Single Self Tuned Fuzzy PID and Two Self Tuned Fuzzy PID controllers.

Table 6.1 Comparison between three controllers

	Position	Rise Time (sec)	Max % overshoot (%)	Settling Time (sec)
PID	**300**	**0.0294**	**69.918**	**0.5759**
	400	**0.0293**	**69.99**	**0.576**
	500	**0.0294**	**70.11**	**0.576**
Single Fuzzy PID	**300**	**0.0491**	**4.096**	**0.184**
	400	**0.04948**	**6.82**	**0.2786**
	500	**0.050364**	**8.91**	**0.3284**
Two Fuzzy PID	**300**	**0.08836**	**0**	**0.1208**
	400	**0.08876**	**0**	**0.1215**
	500	**0.0889**	**0**	**0.1219**

6.4 Conclusion

In this thesis, we studied the Position control of DC Motor by Self tuned Fuzzy PID controller. First we use single Self tuned Fuzzy PID controller then we use two controller method in which we use two Self tuned Fuzzy PID controller. Simulation was carried out using MATLAB to get the output response of the system. The simulation results and the characteristics of both the methods were observed and compared with that of conventional PID controller.

According to the profiling results, the use of above soft-computing techniques resulted in better outputs, dynamic and static characteristics. The response of the system was also faster than in the case of conventional PID controller. The amount of overshoot for the output response was successfully decreased using the above techniques. The application of fuzzy logic to the PID controller imparted it’s the ability to tune itself while operating on-line. Result also show that the Two controller method gives best result at different position and torque. The overshoot is reduced to zero.

6.5 Future scope

MATLAB simulation for position control of DC motor has been done which can be implemented in hardware to observe actual feasibility of the approach applied in this thesis. This technique can be extended to other types of motors. The parameters of PID controller can also be tuned by using genetic algorithm (GA) and Neural Network (NN).

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