SPEED CONTROL OF SEPARATELY EXCITED DC MOTOR USING SELF TUNED FUZZY PID CONTROLLER

A PROJECT THESIS SUBMITTED IN THE FULFILLMENT OF THE

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BACHELOR OF TECHNOLOGY

IN

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Dedication

Dedicated especially to our beloved families, friends and to all our faculty members.

For your care, support and belief in us.

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Sincerely

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Acknowledgement

We would like to articulate our deep gratitude to our project guide **Prof. K. B. Mohanty** who has always been source of motivation and firm support for carrying out the project. We express our gratitude to **Prof. B. D. Subudhi,** Professor and Head of the Department, Electrical Engineering for his invaluable suggestion and constant encouragement all through the thesis work.

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An assemblage of this nature could never have been attempted with our reference to and inspiration from the works of others whose details are mentioned in references section. We acknowledge our indebtedness to all of them. Further, we would like to express our feeling towards our parents and God who directly or indirectly encouraged and motivated us during this dissertation.

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CERTIFICATE

This is to certify that the progress report of the thesis entitled, “SPEED CONTROL OF SEPARATELY EXCITED DC MOTOR USING SELF TUNED FUZZY PID CONTROLLER” submitted by ***Prahlad Kumar Sahoo and Nirmal Kumar Barik*** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Electrical Engineering at the National Institute of Technology Rourkela (Deemed University), is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

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Abstract

In this project we have designed a separately excited DC motor whose speed can be controlled using PID controller. The proportional, integral and derivate (K_P, K_I, K_D) gains of the PID controller are adjusted according to FUZZY LOGIC. First, the fuzzy logic controller is designed according to fuzzy rules so that the systems are fundamentally robust. There are 25 fuzzy rules for self-tuning of each parameter of PID controller. The FLC has two inputs. One is the motor speed error between the reference and actual speed and the second is change in speed error (speed error derivative).Secondly, the output of the FLC i.e. the parameters of PID controller are used to control the speed of the separately excited DC Motor. The study shows that both precise characters of PID controllers and flexible characters of fuzzy controller are present in fuzzy self-tuning PID controller. The fuzzy self-tuning approach implemented on a conventional PID structure was able to improve the dynamic as well as the static response of the system. Comparison between the conventional output and the fuzzy self-tuning output was done on the basis of the simulation result obtained by MATLAB. The simulation results demonstrate that the designed self-tuned PID controller realize a good dynamic behavior of the DC motor, a perfect speed tracking with less rise and settling time, minimum overshoot, minimum steady state error and give better performance compared to conventional PID controller.

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List of Abbreviation

AC: Alternating Current

DC: Direct Current

FLC: Fuzzy logic controller

MF: Membership Function

PI: Proportional Integral

PD: Proportional Derivative

PID: Proportional Integral Derivative

SSE: Steady State Error

MATLAB: Matrix Laboratory

Chapter 1

Introduction

1.1: Introduction

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 drives, because of their simplicity, ease of application, high reliabilities, flexibilities and favorable cost have long been a backbone of industrial applications, robot manipulators and home appliances where speed and position control of motor are required. DC drives are less complex with a single power conversion from AC to DC. Again the speed torque characteristics of DC motors are much more superior to that of AC motors. A DC motors provide excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition of use as adjustable speed machines and a 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 controllers can be: proportional integral (PI), proportional integral derivative (PID) Fuzzy Logic Controller (FLC) or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Swarm[10]. The proportional – integral – derivative (PID) controller operates the majority of the control system in the world. It has been reported that more than 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 the PID controller [3], [4]. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly.

The major problems in applying a conventional control algorithm (PI, PD, PID) in a speed controller are the effects of non-linearity in a DC motor. The nonlinear characteristics of a DC motor such as saturation and fiction could degrade the performance of conventional controllers [1], [2].Generally, an accurate nonlinear model of an actual DC motor is difficult to find and parameter obtained from systems identification may be only approximated values. The field of Fuzzy control has been making rapid progress in recent years. Fuzzy logic control (FLC) is one of the most successful applications of fuzzy set theory, introduced by L.A Zadeh in 1973 and applied (Mamdani 1974) in an attempt to control system that are structurally difficult to model.

Since then, FLC has been an extremely active and fruitful research area with many industrial applications reported [5].In the last three decades, FLC has evolved as an alternative or complementary to the conventional control strategies in various engineering areas. Fuzzy control theory usually provides non-linear controllers that are capable of performing different complex non-linear control action, even for uncertain nonlinear systems. Unlike conventional control, designing a FLC does not require precise knowledge of the system model such as the poles and zeroes of the system transfer functions. Imitating the way of human learning, the tracking error and the rate change of the error are two crucial inputs for the design of such a fuzzy control system [6], [7].

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1.2:Where FLC is used?

- The description of the technological process is available only in word form, not in analytical form.
- It is not possible to identify the parameters of the process with precision.
- The description of the process is too complex and it is more reasonable to express its description in plain language words.
- The controlled technological process has a “fuzzy” character, i.e. its behavior is not fully unequivocal under precisely defined conditions.
- Or it is not possible to precisely define these conditions.[8]

1.3: Advantages of using fuzzy technique

- Simplicity of control and Smooth operation
- High degree of tolerance
- Low cost
- Reduce the effect of Non-linearity
- Inherent approximation capability
- Possibility to design without knowing the exact mathematical model of the process

PID controllers can be tuned in different ways e.g. Hand-tuning, Ziegler-Nichols tuning, loop shaping, analytical methods, by optimization, pole placement, or self-tuning. Using fuzzy control rules PID parameters "K_P", "K_I", "K_D" are adjusted, which constitute a self-tuned fuzzy PID controller.

Chapter 2

Separately excited DC motor

2.1: Speed control of separately excited dc motor

The term speed control stand for intentional speed variation carried out manually or automatically DC motors are most suitable for wide range speed control and are there for many adjustable speed drives.

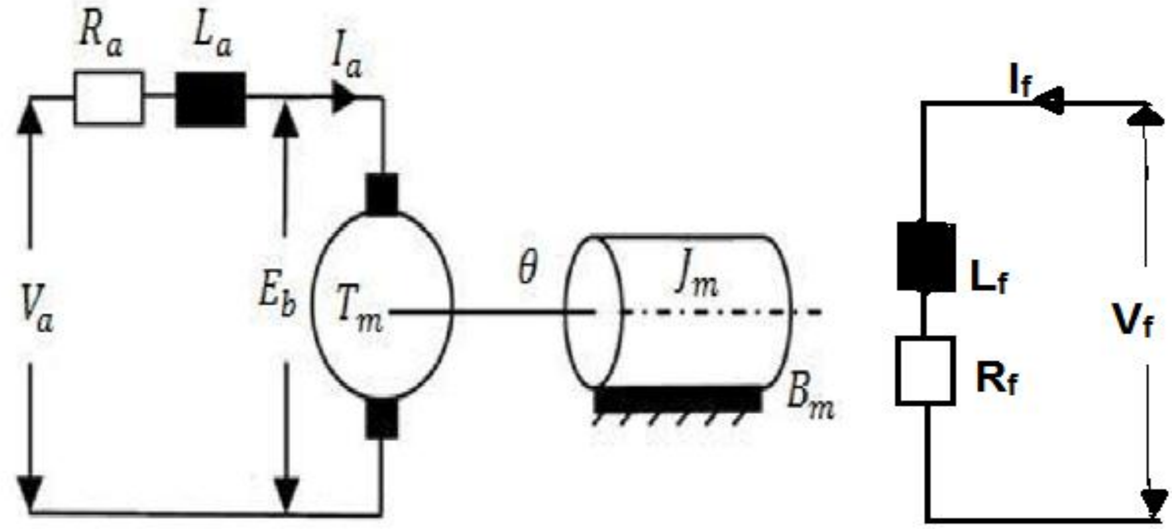


Figure.1: Separately excited DC motor model

Where

- V_a is the armature voltage. (In volt)
- E_b is back emf the motor (In volt)
- I_a is the armature current (In ampere)
- R_a is the armature resistance (In ohm)
- L_a is the armature inductance (In henry)
- T_m is the mechanical torque developed (In Nm)
- J_m is moment of inertia (In kg/m²)
- B_m is friction coefficient of the motor (In Nm/ (rad/sec))
- ω is angular velocity (In rad/sec)

We know that

$\omega \; \alpha \; (V_a - I_aR_a)/\phi$

=> $\omega = (V_a - I_aR_a)/K_a\phi$ ……………………….. (1)

Where ϕ = Field flux per pole

K_a= Armature constant = $PZ/2\pi a$

Where P = No. of pole

Z = Total no. of armature conductor

a = No. of parallel path

From the equation (1) it is clear that for DC motor there are basically 3 method of speed control.

They are:-

1- Variation of resistance in armature circuit.
2- Variation of field flux.
3- Variation of armature terminal voltage.

2.2: Modeling of separately excited dc motor

From figure 1:

The armature voltage equation is given by:

$V_a = E_b + I_aR_a + L_a\,(dI_a/dt)$

Now the torque balance equation will be given by:

$T_m = J_m d\omega/dt + B_m\omega + T_L$

Where:

T_L is load torque in Nm.

Friction in rotor of motor is very small (can be neglected), so B_m= 0

Therefore, new torque balance equation will be given by:

$T_m = J_m d\omega/dt + T_L$ --------- (i)

Taking field flux as Φ and Back EMF Constant as K. Equation for back emf of motor will be:

$E_b = K \Phi \omega$ --------- (ii)

Also, $T_m = K \Phi I_a$--------- (iii)

Taking laplace transform of the motor's armature voltage equation we get

$$I_a(S) = (V_a - E_b)/ (R_a + L_aS)$$

Now, taking equation (ii) into consideration, we have:

= $I_a(s) = (V_a - K\Phi\omega)/ R_a (1+ L_aS/R_a)$

And $\omega(s) = (T_m - T_L) /JS = (K\Phi I_a - T_L) /J_mS$

(Armature Time Constant) $T_a= L_a/R_a$

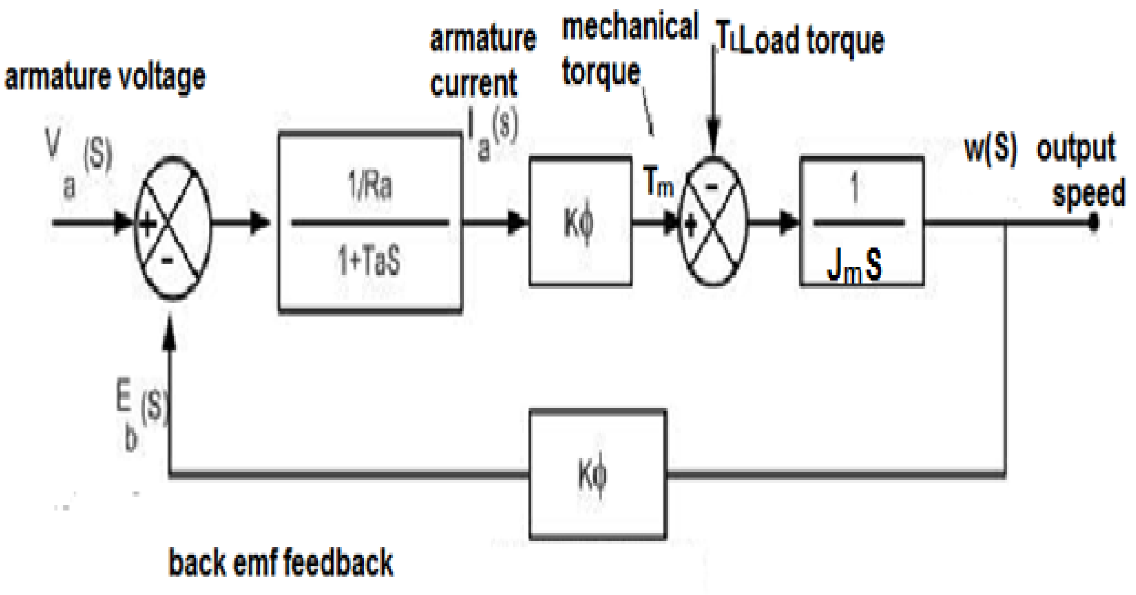


Figure 2: Block Model of Separately Excited DC Motor

After simplifying the above motor model, the overall transfer function will be

$$\omega (s) / V_a(s) = [K\Phi /R_a] /J_mS(1+T_aS) /[1 +(K^2\Phi^2 /R_a) /J_mS(1+T_aS)]$$

Further simplifying the above transfer function:

$\omega(s) / V_a(s) = (1 / k\Phi) / \{ 1 + (k^2\Phi^2 / R_a) / J_m S(1+T_a S)\}$ ---------------- (iv)

Assuming, $T_{em} = J_m R_a / (k\Phi)^2$ as electromechanical time constant.

Then the above transfer function can be written as:

$\omega(s) / V_a(s) = (1/k\Phi) / [S T_{em} (1+S T_a)+1]$ --------(v)

Let us assume that during starting of motor, load torque $T_L = 0$ and applying full voltage V_a

Also assuming negligible armature inductance, the basic armature voltage equation can be written as:

$$V_a = K\Phi\omega(t) + I_a R_a$$

At the same time Torque equation will be:

$T_m = J_m d\omega/dt = K\Phi I_a$ ----- (vi)

Putting the value of I_a in above armature equation:

$$V_a = K\Phi\omega(t) + (J_m d\omega/dt) R_a / K\Phi$$

Dividing on both sides by $K\Phi$,

$V_a/K\Phi = \omega(t) + J_m R_a (d\omega/dt)/(K\Phi)^2$ ------------------------(vii)

$V_a/K\Phi$ is the value of motor speed under no load condition. Therefore,

$$\omega(\text{no load}) = \omega(t) + J_m R_a (d\omega/dt)/(K\Phi)^2 = \omega(t) + T_{em} (d\omega/dt)$$

Where, $K\Phi = K_m$ (say)

And $T_{em} = J_m R_a / (K\Phi)^2 = J R_a / (K_m)^2$

Therefore, $J_m = T_{em} (K_m)^2 / R_a$ --------- (viii)

From motor torque equation, we have:

$\omega(s) = K_m I_a(s)/JS - T_L/J_m S$ -------- (ix)

From equation (viii) and (ix), we have:

$$\omega(s) = [(R_a / K_m) I_a(s) - T_L R_a / (K_m)^2] (1/T_{em}(s))$$

Now, Replacing KΦ by K_m in equation (v), we will get:

$\omega(s) / V_a(s) = (1/K_m) / (1+ST_{em}+S^2T_aT_{em})$ ------------ (x)

The armature time constant T_a is very much less than the electromechanical time constant T_{em}, ($T_a << T_{em}$)

Simplifying, $1 + ST_{em} + S^2T_aT_{em} \approx 1 + S(T_a+T_{em}) + S^2T_aT_{em} = (1 + ST_{em})(1 + ST_a)$

The equation can be written as:

$$\omega(s) / V_a(s) = (1/K_m)/((1 + ST_{em})(1 + ST_a)) \quad \text{-----(xi)}$$

T_{em} and T_a are the time constants of the above system transfer function which will determine the response of the system. Hence the dc motor can be replaced by the transfer function obtained in equation (xi) in the DC drive model.

2.3: Specification of the separately excited DC Motor

Armature resistance (R_a) = 0.5Ω

Armature inductance (L_a) = 0.02 H

Armature voltage (V_a) = 200 V

Mechanical inertia (j_m) = 0.1 $Kg.m^2$

Friction coefficient (B_m) = 0.008 N.m/rad/sec

Back emf constant (k) = 1.25 V/rad/sec

Rated speed = 1500 r.p.m

Motor torque constant=N.m/A

2.3.1: Calculation

Speed at full load when "ω=157.07 rad/sec"

E_b=1.25x157.07=196.3 V

$V_a = E_b+I_aR_a$

$200 = 196.3+I_aR_a$

I_a =7.325 Amps

Chapter 3

Fuzzy Theory

3.1: The beginning of fuzzy set

Fuzzy theory was initiated by Lotfi A. Zadeh in 1965 as an extension of the classical control theory. According to him classical control theory put too much emphasis on precision and therefore could not the complex systems. Later he formalized the ideas into the paper “Fuzzy set.” Fuzzy sets are sets whose elements have degrees of membership.

3.2: If-Then rules of fuzzy systems

Fuzzy systems are knowledge based or rule based systems. The heart of a fuzzy system is a knowledge base consisting of the so- called If-Then rules. A fuzzy If-Then statement in which some words are characterized by continuous membership functions. After defining the fuzzy sets and assigning their membership functions, rules must be written to describe the action to be taken for each combination of control variables. These rules will relate the input variables to the output variable using If-Then statements which allow decisions to be made. The If (condition) is an antecedent to the Then (conclusion) of each rule. Each rule in general can be represented in the following manner:

If (antecedent) Then (consequence).

For example:

If the speed of the car is high, then apply less force to the accelerator.

If pressure is high, then volume is small

3.3: Difference between classical set and fuzzy set

Let U be the universe of discourse, or universal set which contains all the possible elements of concern in each particular context or application.

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

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

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 $\mu_A(x)$,such that

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

Crisp sets are binary in nature.

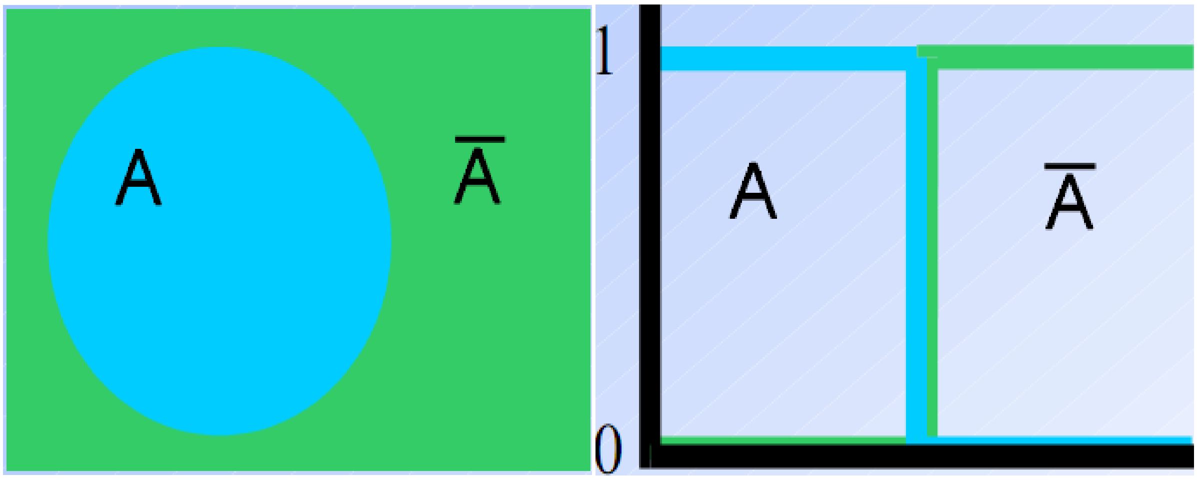


Figure 3: Venn diagram and grade of belonging of crisp set A

3.3.2: Fuzzy set

A fuzzy set in a universe of discourse U is characterized by a membership function $\mu_A(x)$ that takes values in the interval [0, 1].

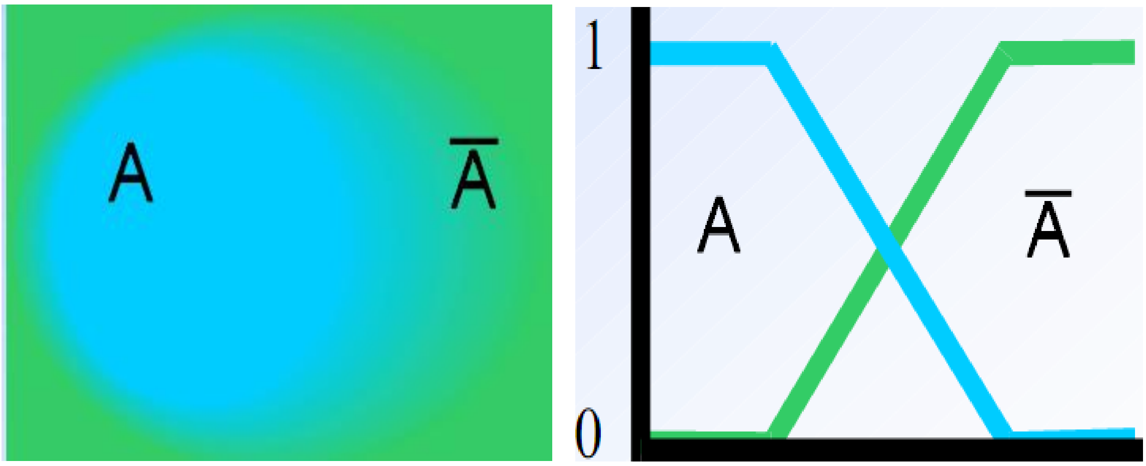
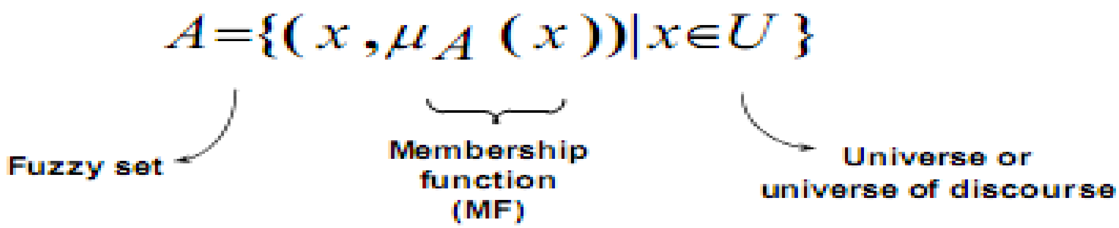


Figure 4: Venn diagram and grade of belonging of fuzzy set A

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



3.4: Fuzzy sets with a continuous universe

Let A be a fuzzy set named “numbers closed to zero.” Then a possible membership function for A is

$$\mu_A(x) = e^{-x2}$$

Where x ϵ According to this membership function, the number 0 and 2 belong to the fuzzy set to degrees of $e^0=1$ and e^{-4} ,respectively

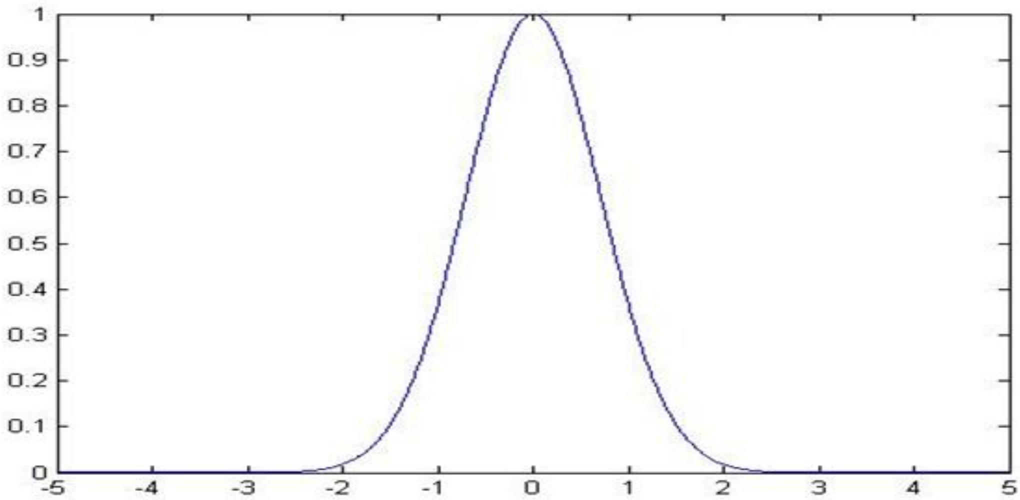


Figure 5: A possible membership function to characterize “number close to zero”

So the construction of fuzzy set depends on two things:

(1) The identification of suitable universe of discourse.

(2) The specification of an approximate MF’s. As MF’s are subjective, which means MF’s are specified for the some concept.

3.5: Operations on fuzzy sets

Union, intersection and compliment are the most basic operation on classical sets on the basic of these three operations, a number of identities can be established. Corresponding to the ordinary set operations of union, intersection and compliment, fuzzy sets have similar operation.

Let us take two fuzzy set A and B to define different operation.

Where

A= {x|x is near an integer}

B= {x|x is close to 2}

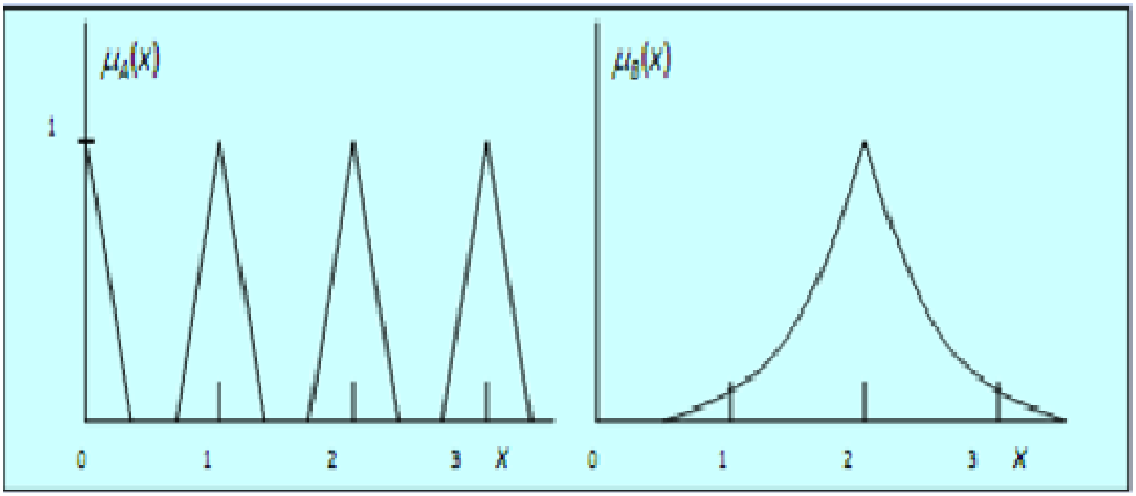


Figure 6**:** Membership function of set A and B

3.5.1: 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

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

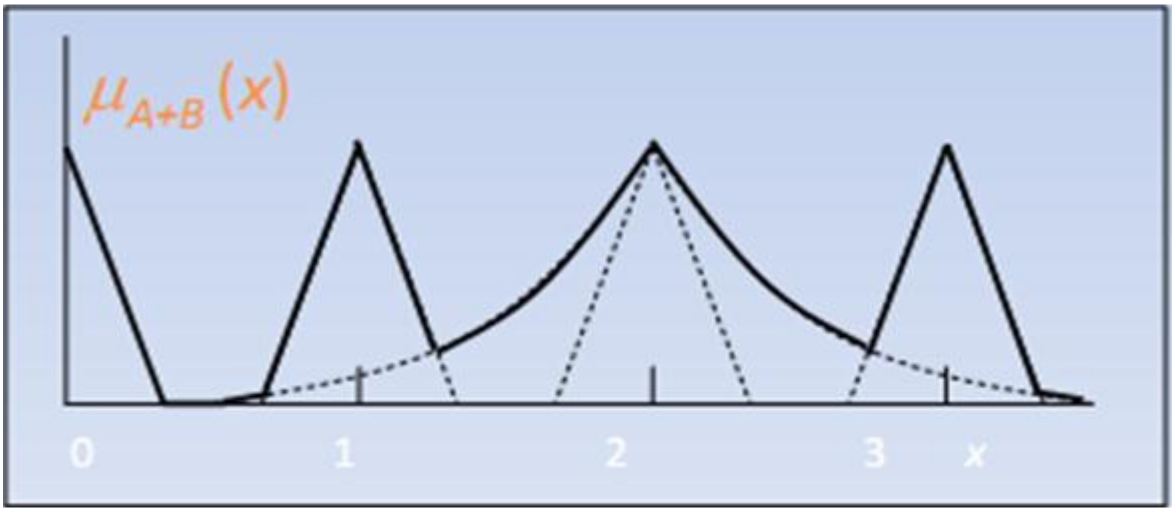


Figure 7: Membership function for A + B

3.5.2: 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

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

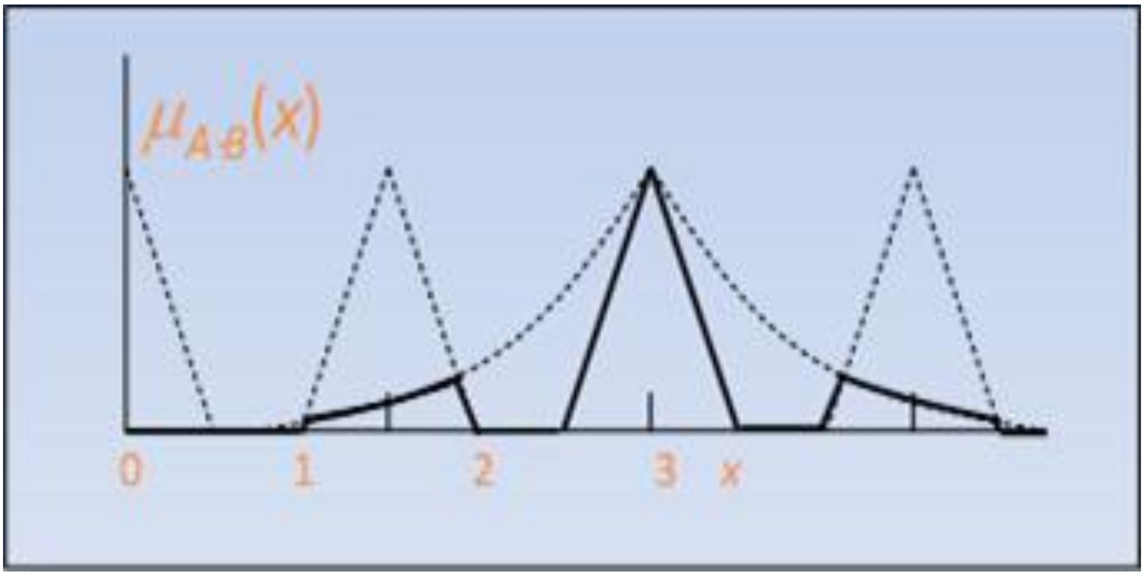


Figure 8: Membership function for A. B

3.5.3: 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}

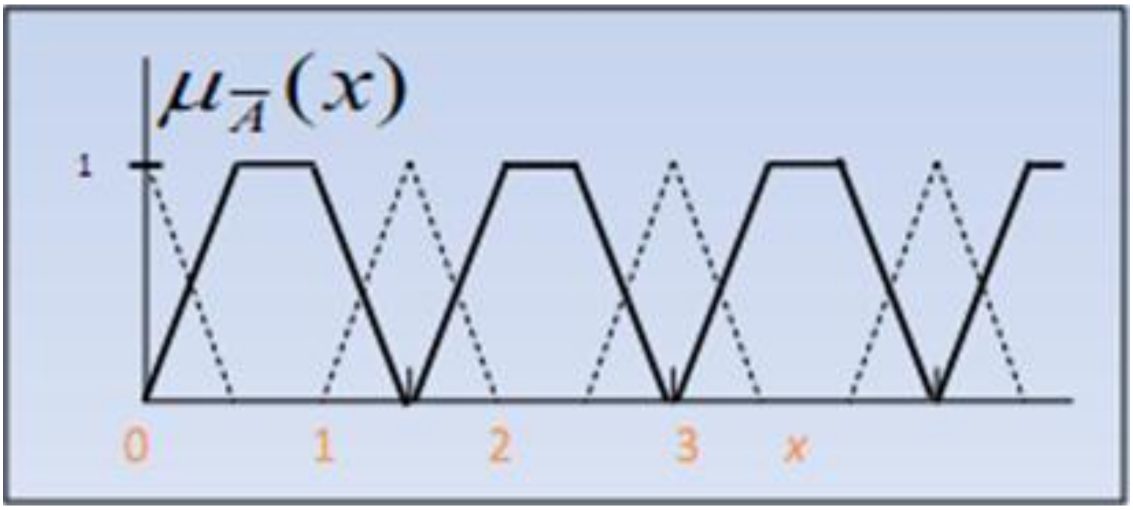


Figure 9: Membership function for A and complement of A

3.5.4: 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

$\mu_A(x) \leq \mu_B(x)$ for all x.

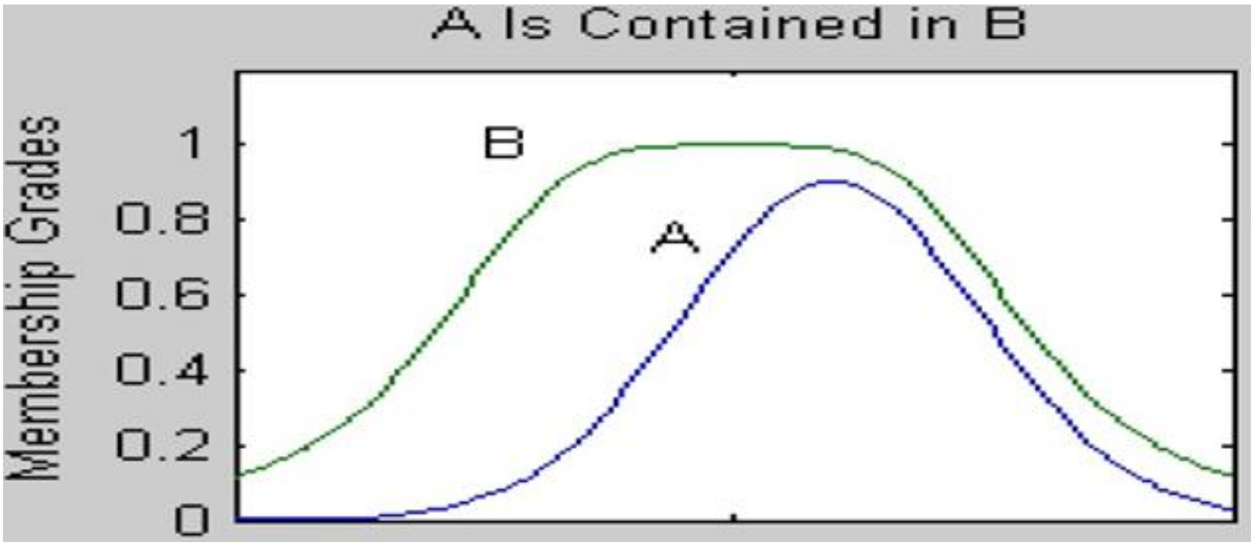


Figure 10: Set A is the subset of B

$A \leq B \leftrightarrow \mu_A(x) \leq \mu_B(x).$

3.6: What is fuzzy logic?

Fuzzy logic is the superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth -- truth values between “completely true" and "completely false". It is made possible through the concept of degree of membership.

3.7: Basic terminology in fuzzy logic

3.7.1: 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%.

3.7.2: Membership Function

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

How to determine the MFs?

- Use the knowledge of human experts
- Data collected from various sensors

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.

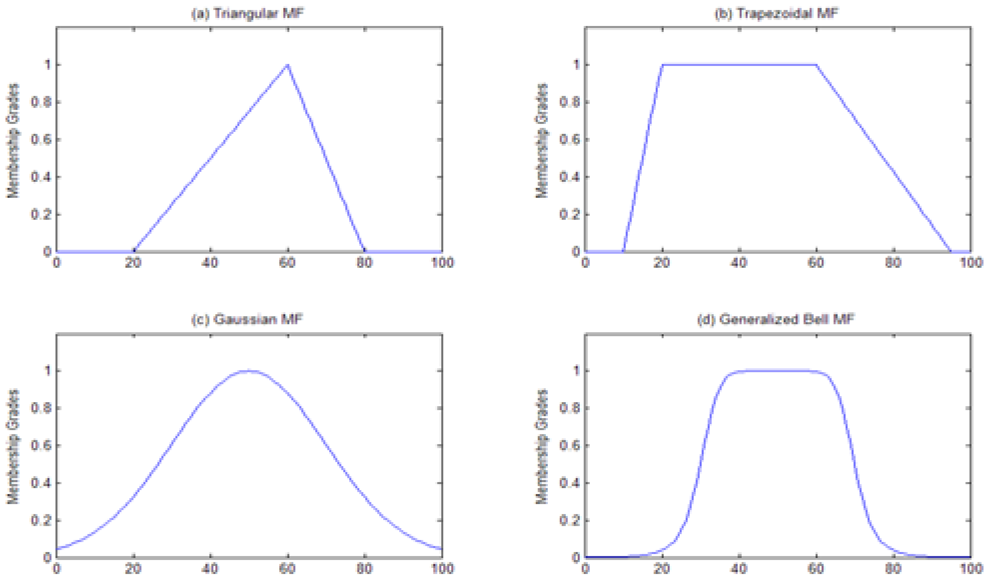


Figure 11: Shape of different membership function

3.7.3: 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 25^0C, an output voltage of 5.35 V etc.

3.7.4: 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.

3.8: How does FL work?

FL requires some numerical parameters in order to operate such as what is considered significant error and significant rate-of-change-of-error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them. For example, a simple temperature control system could use a single temperature feedback sensor whose data is subtracted from the command signal to compute "error" and then time-differentiated to yield the error slope or rate-of-change-of-error, hereafter called "error-dot". Error might have units of degs F and a small error considered to be 2F while a large error is 5F. The "error-dot" might then have units of degs/min with a small error-dot being 5F/min and a large one being 15F/min. These values don't have to be symmetrical and can be "tweaked" once the system is operating in order to optimize performance.

3.9: Why fuzzy systems?

Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. The reason for which is very simple. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design. Other approaches require accurate equations to model real-world behaviors; fuzzy logic can accommodate the ambiguities of real-world human language and logic. It provides both an intuitive method for describing systems in human terms and automates the conversion of those system specifications into effective models

3.10: Application area of fuzzy logic

1: Controller application

2: Communication engineering

3: Image processing

4: Production engineering

5: System identification

6: Consumer electronics

Chapter 4

Fuzzy Controller

4.1: Fuzzy logic controller (FLC)

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. The operation of a FLC is based on qualitative knowledge about the system being controlled .It doesn't need any difficult mathematical calculation like the others control system. While the others control system use difficult mathematical calculation to provide a model of the controlled plant, it only uses simple mathematical calculation to simulate the expert knowledge

The requirement for the application of a FLC arises mainly in situations where:

- The description of the technological process is available only in word form, not in analytical form.
- It is not possible to identify the parameters of the process with precision.
- The description of the process is too complex and it is more reasonable to express its description in plain language words.
- The controlled technological process has a “fuzzy” character.
- It is not possible to precisely define these conditions.

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

a) Fuzzification

b) Inference engine

c) Rule base

d) Defuzzification

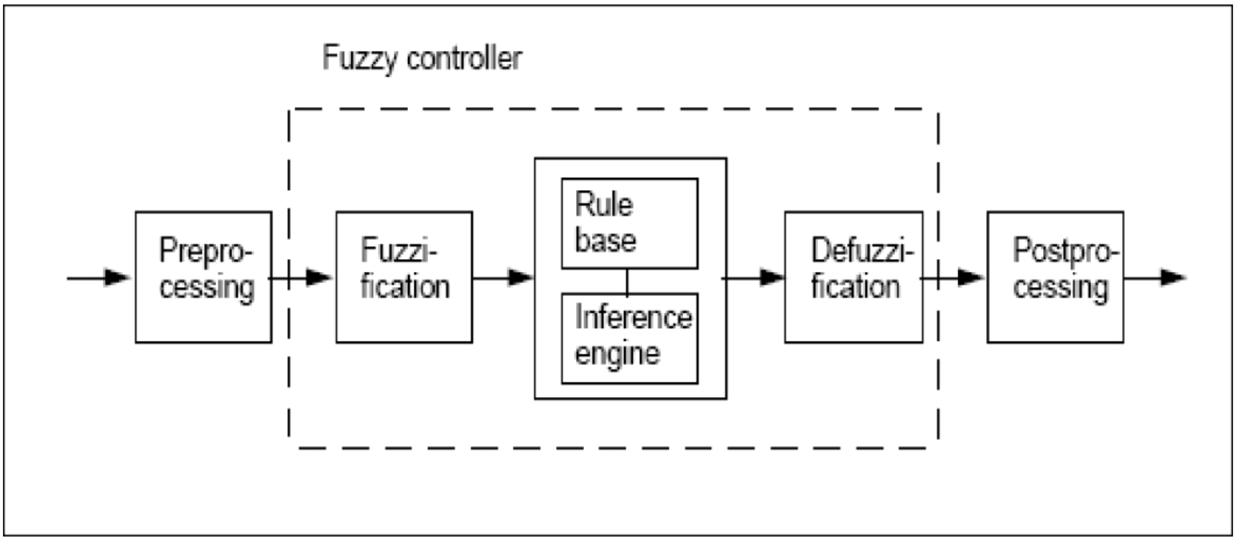


Figure 12: Structure of fuzzy logic controller

4.2: 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

4.3: Rule base

A decision making logic which is, simulating a human decision process, inters fuzzy control action from the knowledge of the control rules and linguistic variable definitions [9]. 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 [14].

4.4: Inference engine

Inference engine is defined as the Software code which processes the rules, cases, objects or other type of knowledge and expertise based on the facts of a given situation. When there is a problem to be solved that involves logic rather than fencing skills, we take a series of inference steps that may include deduction, association, recognition, and decision making. An inference engine is an information processing system (such as a computer program) that systematically employs inference steps similar to that of a human brain.

4.5: Defuzzification

The reverse of Fuzzification is called Defuzzification. The use of Fuzzy 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 [11]:

1) Center of gravity (COG)
2) Bisector of area (BOA)
3) Mean of maximum (MOM)

4.5.1: Center of gravity (COG)

For discrete sets COG is called center of gravity for singletons (COGS) where the crisp control value is the abscissa of the center of gravity of the fuzzy set is calculated as follows:

$$u_{COGS} = \frac{\sum_i \mu_c(x_i) x_i}{\sum_i \mu_c(x_i)}$$

Where x_i is a point in the universe of the conclusion (i=1, 2, 3…) and μ_c (x_i) is the membership value of the resulting conclusion set. For continuous sets summations are replaced by integrals.

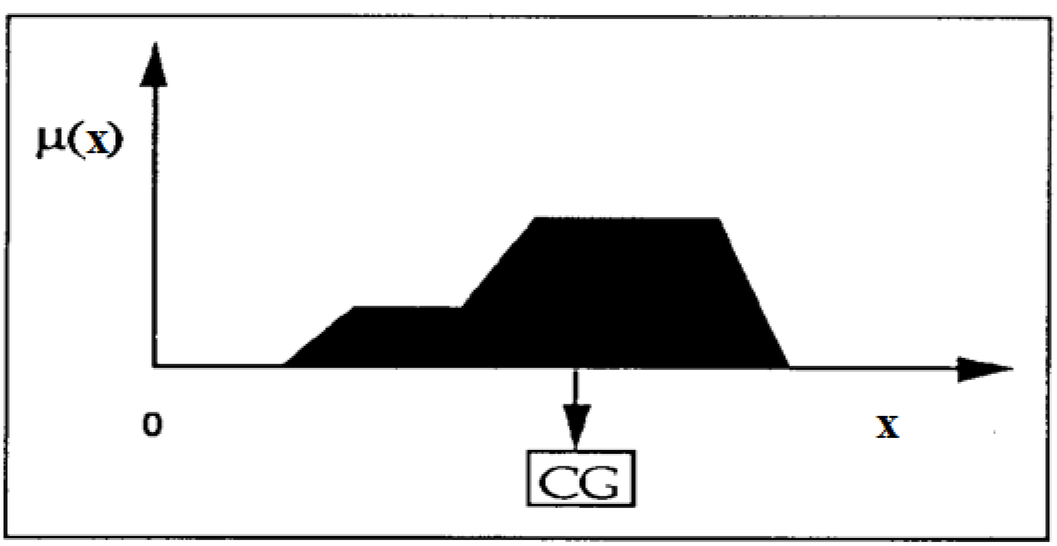


Figure 13: Illustration of centre of gravity method

4.5.2: Bisector of area (BOA)

The bisector of area (BOA) defuzzification method calculates the abscissa of the vertical line that divides the area of the resulting membership function into two equal areas. For discrete sets, u_{BOA} is the abscissa x_j that minimizes

$$\left|\sum_{i=1}^{j} \mu_c(x_i) - \sum_{i=j+1}^{i_{max}} \mu_c(x_i)\right|, \quad i < j < i_{max}$$

Here i_{max} is the index of the largest abscissa $x_{i_{max}}$. BOA is a computationally complex method.

4.5.3: Mean of maximum (MOM)

In this method the crisp value is to choose the point with the highest membership. There may be several points in the overall implied fuzzy set which have maximum membership value. Therefore it's a common practice to calculate the mean value of these points. This method is called mean of maximum (MOM) and the crisp value is calculated as follows:

$$u_{MOM} = \frac{\sum_{i \in I} x_i}{|I|}, \quad I = \{i \mid \mu_c(x_i) = \mu_{max}\}$$

Here I is the (crisp) set of indices i where $\mu_c(x_i)$ reaches its maximum μ_{max}, and $|I|$ is its cardinality (the number of members).

Implementation of an FLC requires the choice of four key factors

1: Number of fuzzy sets that constitute linguistic variables.

2: Mapping of the measurements onto the support sets.

3: Control protocol that determines the controller behavior.

4: Shape of membership functions.

Chapter 5

Fuzzy Controller Design

5.1: Fuzzy logic controller

The input to the Self-tuning Fuzzy PID Controller are speed error "e(t)" and Change-in-speed error "de(t)". The input shown in figure are described by

$$e\ (t)=w_r(t)-w_a(t)$$

$$de\ (t)=e(t)-e(t-1)$$

Using fuzzy control rules on-line, PID parameters “K_P",” K_I",” K_D" are adjusted, which constitute a self-tuning fuzzy PID controller as shown in Figure 15.

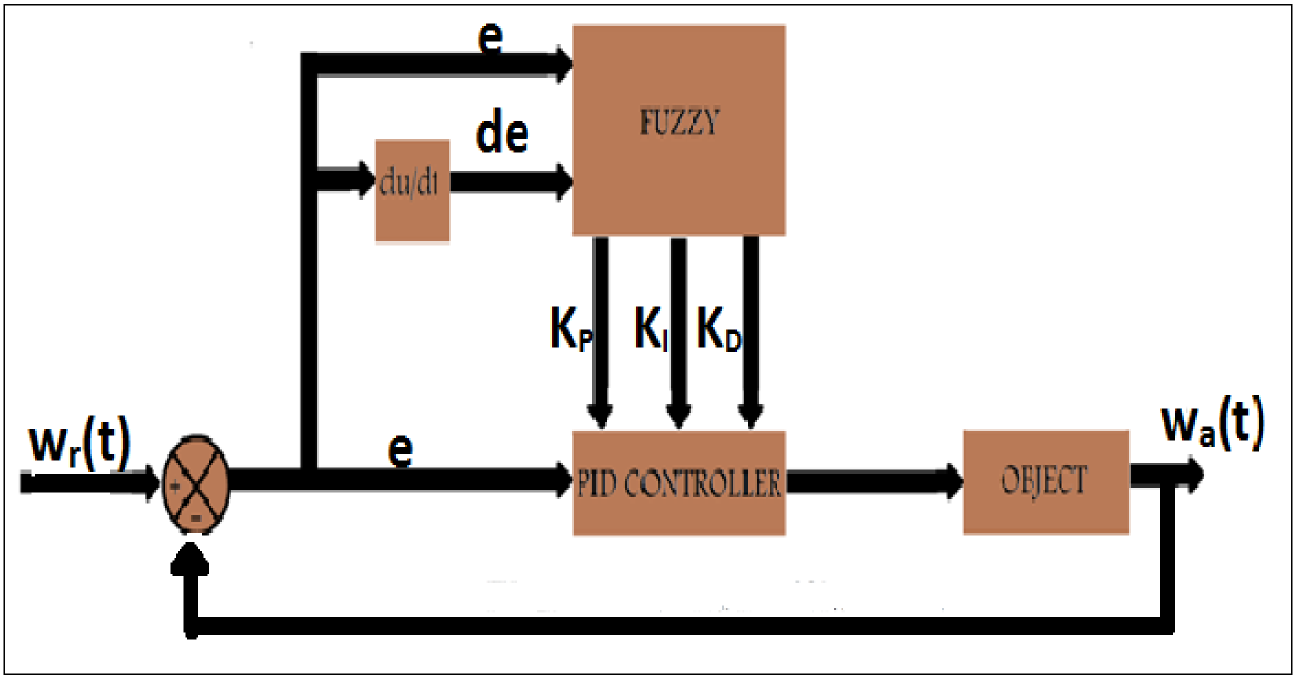


Figure 15: The structure of self-tuning fuzzy PID controller

PID parameters fuzzy self-tuning is to find the fuzzy relationship between the three parameters of PID and "e" and "de", and according to the principle of fuzzy control, to modify the three parameters in order to meet different requirements for control parameters when "e" and "de" are different, and to make the control object a good dynamic and static performance [12].

5.1.1: Adjusting fuzzy membership functions and rules

In order to improve the performance of FLC, the rules and membership functions are adjusted. 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 [15]. An experiment to study the effect of rise time (T_r), maximum overshoot (M_p) and steady-state error (SSE) when varying K_P, K_I and K_D was conducted. The results of the experiment were used to develop 25-rules for the FLC of K_P, K_I and K_D.

5.2: Design of Membership Function (MF)

5.2.1: Input Variables

5.2.1.1: Fuzzy sets of speed error (e) variable

Table 1: Membership function of speed error

Fuzzy set (Label)	Description	Numerical Range	Shape of Membership Function
Negative large (NL)	Large Speed difference in negative direction	-20 to -20 -20 to 40	Triangular
Negative small (NS)	Small Speed difference in negative direction	10 to 40 40 to 100	Triangular
Zero (ZE)	Speed difference is zero	40 to 70 70 to 100	Triangular
Positive Small (PS)	Small Speed difference in positive direction	40 to 100 100 to 130	Triangular
Positive large (PL)	Large Speed difference in positive direction	100 to 160 160 to 160	Triangular

5.2.1.2: Fuzzy sets of change in speed error (de) variable

Table 2: Membership function of change in speed error.

Fuzzy set (Label)	Description	Numerical Range	Membership Function
Negative large (NL)	Large error difference in negative direction	-1300 to -1300 -1300 to -800	Triangular
Negative small (NS)	Small error difference in negative direction	-1050 to -800 -800 to -300	Triangular
Zero (ZE)	Error difference is zero	-800 to -550 -550 to -300	Triangular
Positive Small (PS)	Small error difference in positive direction	-800 to -300 -300 to -50	Triangular
Positive large (PL)	Large error difference in positive direction	-300 to -300 -300 to 200	Triangular

5.2.2: Output Variables

5.2.2.1: Fuzzy sets for K_P

Table 3: Membership function proportional gain K_P.

Fuzzy set (Label)	Numerical Range	Membership function
Positive very small (PVS)	0 to 0 0 to 10	Triangular
Positive Small (PS)	0 to 5 5 to 15	Triangular
Positive Medium small (PMS)	5 to 10 10 to 20	Triangular
Positive Medium (PM)	10 to 15 15 to 20	Triangular
Positive Medium Large (PML)	10 to 20 20 to 25	Triangular
Positive Large (PL)	15 to 25 25 to 30	Triangular
Positive very Large (PVL)	20 to 30 30 to 30	Triangular

5.2.2.2: Fuzzy sets for K_I

Table 4: Membership function integral gain K_I.

Fuzzy set (Label)	Numerical Range	Membership function
Positive very small (PVS)	0 to 0 0 to 20	Triangular
Positive Small (PS)	0 to 10 10 to 30	Triangular
Positive Medium small (PMS)	10 to 20 20 to 40	Triangular
Positive Medium (PM)	20 to 30 30 to 40	Triangular
Positive Medium Large (PML)	20 to 40 40 to 50	Triangular
Positive Large (PL)	30 to 50 50 to 60	Triangular
Positive very Large (PVL)	40to 60 60 to 60	Triangular

5.2.2.3: Fuzzy sets for K_D

Table 5: Membership function derivative gain K_D.

Fuzzy set (Label)	Numerical Range	Shape of Membership function
Positive very small (PVS)	0 to 0 0 to 2	Triangular
Positive Small (PS)	0 to 1 1 to 3	Triangular
Positive Medium small (PMS)	1 to 2 2 to 4	Triangular
Positive Medium (PM)	2 to 3 3 to 4	Triangular
Positive Medium Large (PML)	2 to 4 4 to 5	Triangular
Positive Large (PL)	3 to 5 5 to 6	Triangular
Positive very Large (PVL)	4 to 6 6 to 6	Triangular

5.3: Design of Fuzzy Rules

5.3.1: Rule bases for tuning K_P

Table 6: Fuzzy rule table for K_P

de/e	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

5.3.2: Rule bases for tuning K_I

Table 7: Fuzzy rule table for K_I

de/e	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

5.3.3: Rule bases for tuning K_D

Table 8: Fuzzy rule table for K_D

de/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	PVL	PVL	PVL	PVL
PL	PVL	PVL	PVL	PVL	PVL

Chapter 6

MATLAB Simulation

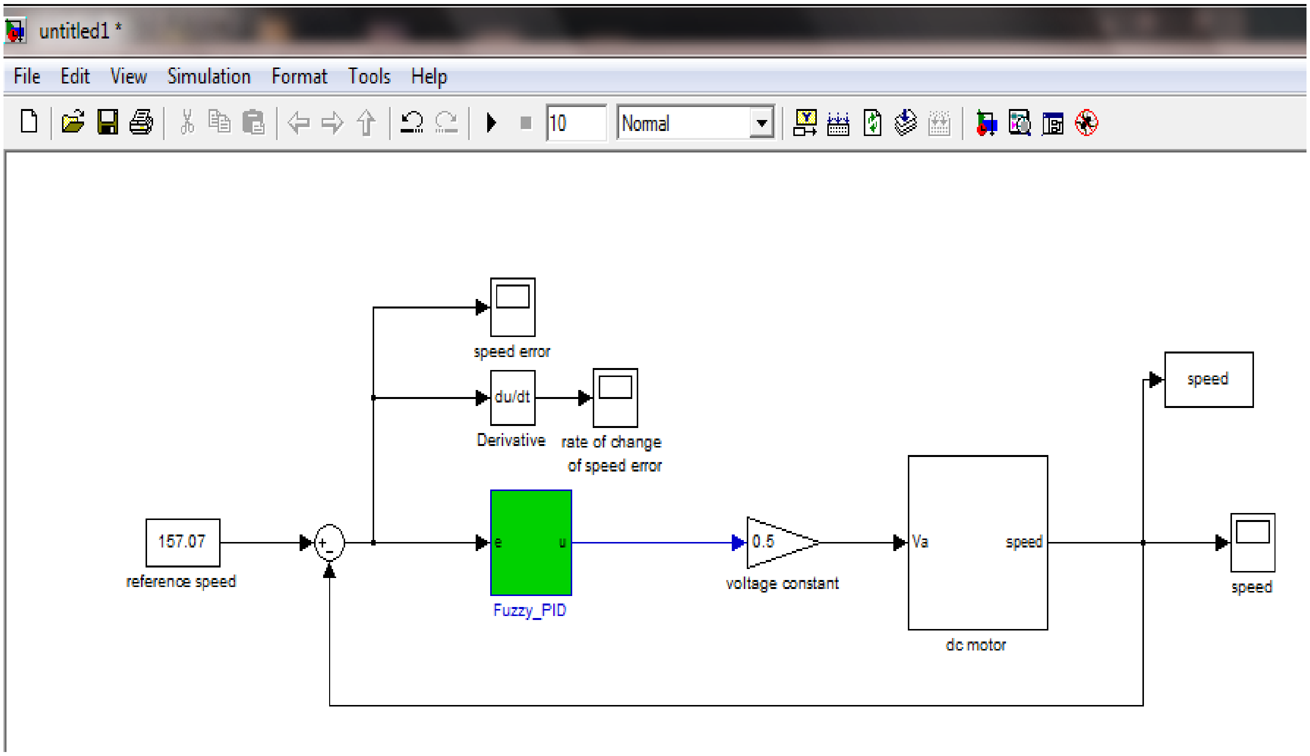


Figure 16: Simulink Model for Speed Control of Separately Excited DC motor using self tuned fuzzy PID controller

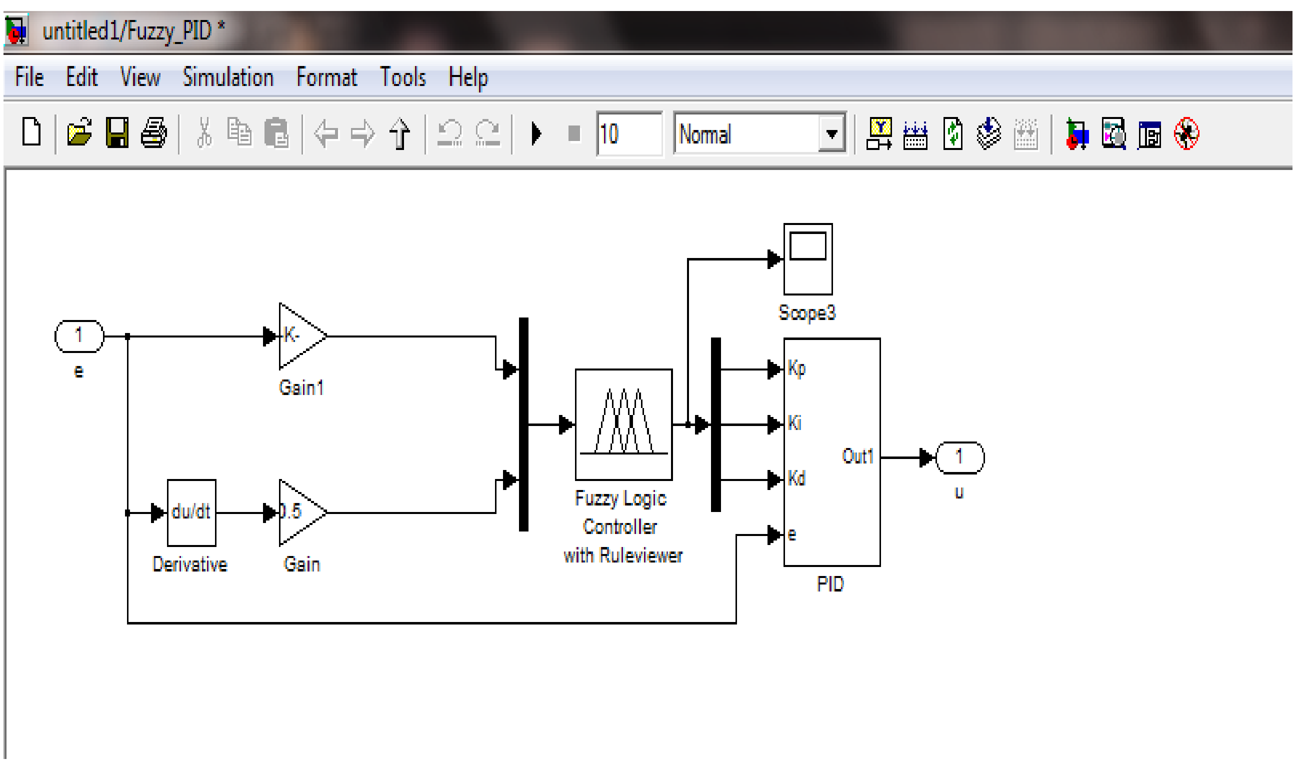


Figure 17: Simulink model of fuzzy-PID controller

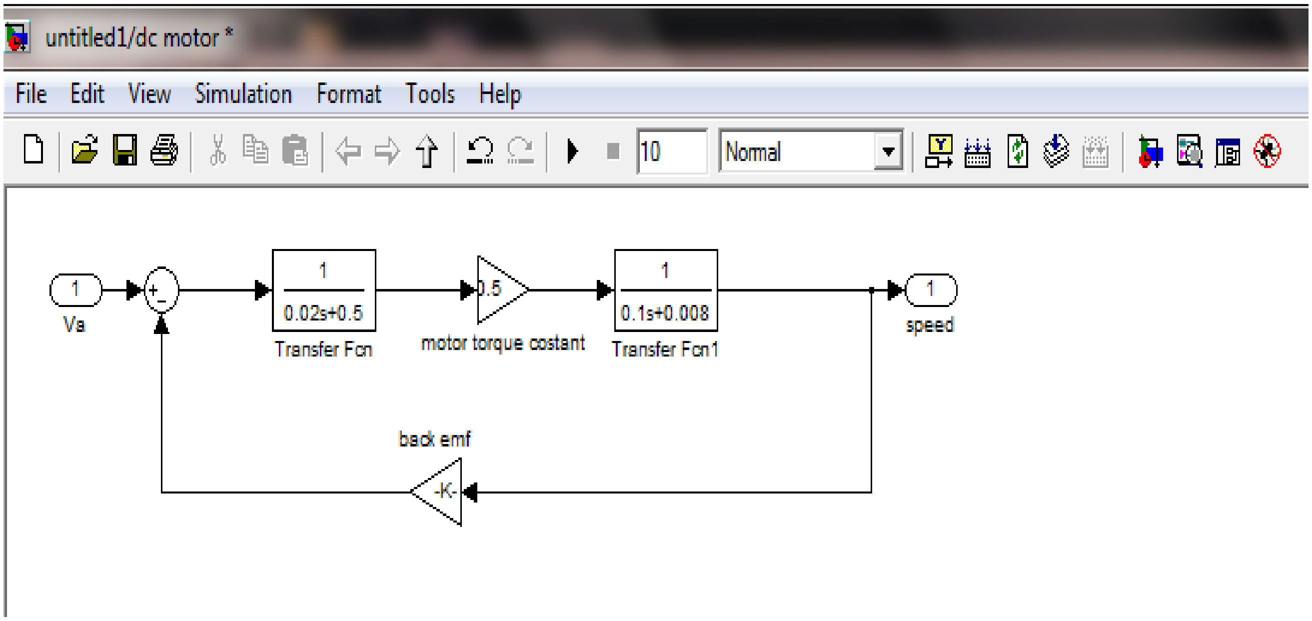


Figure 18: Model of separately excited dc motor

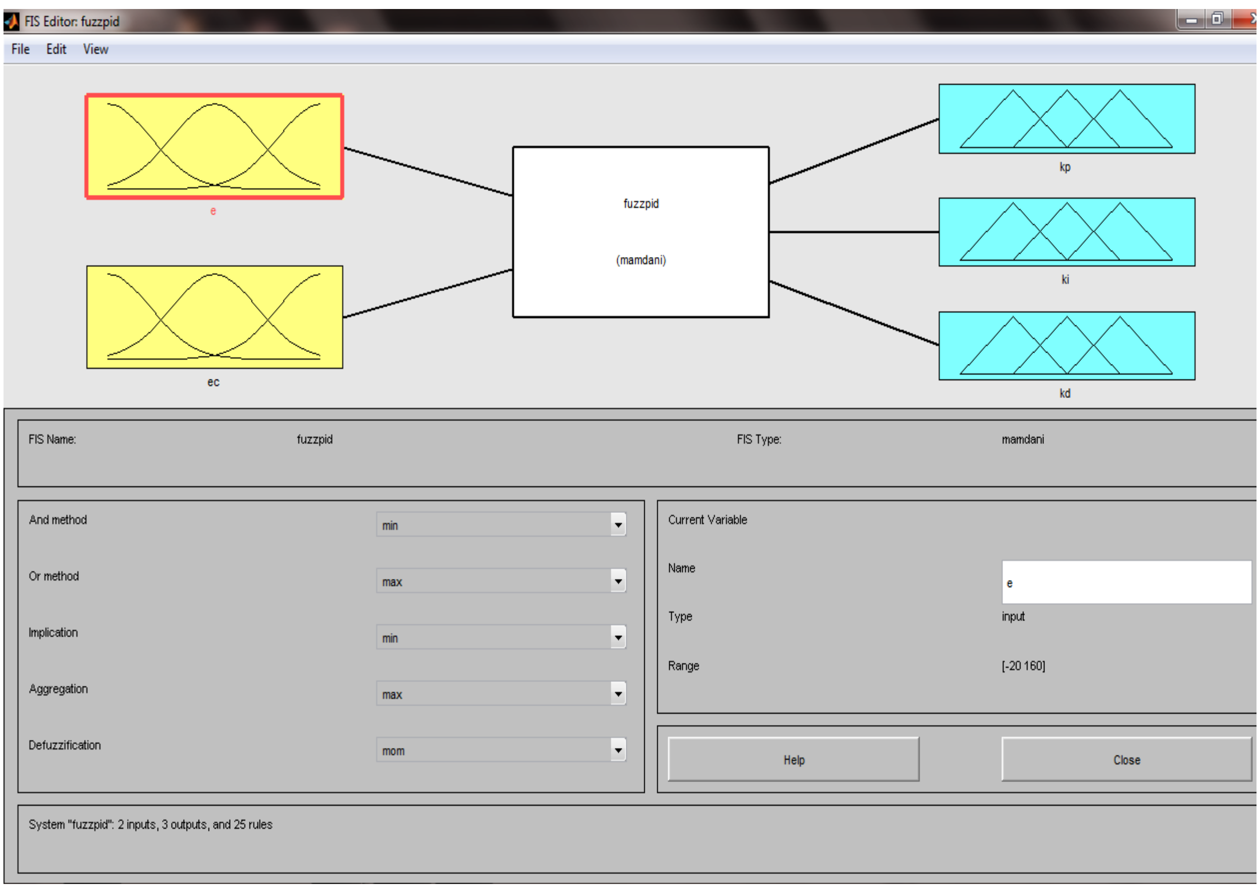


Figure 19: FIS editor

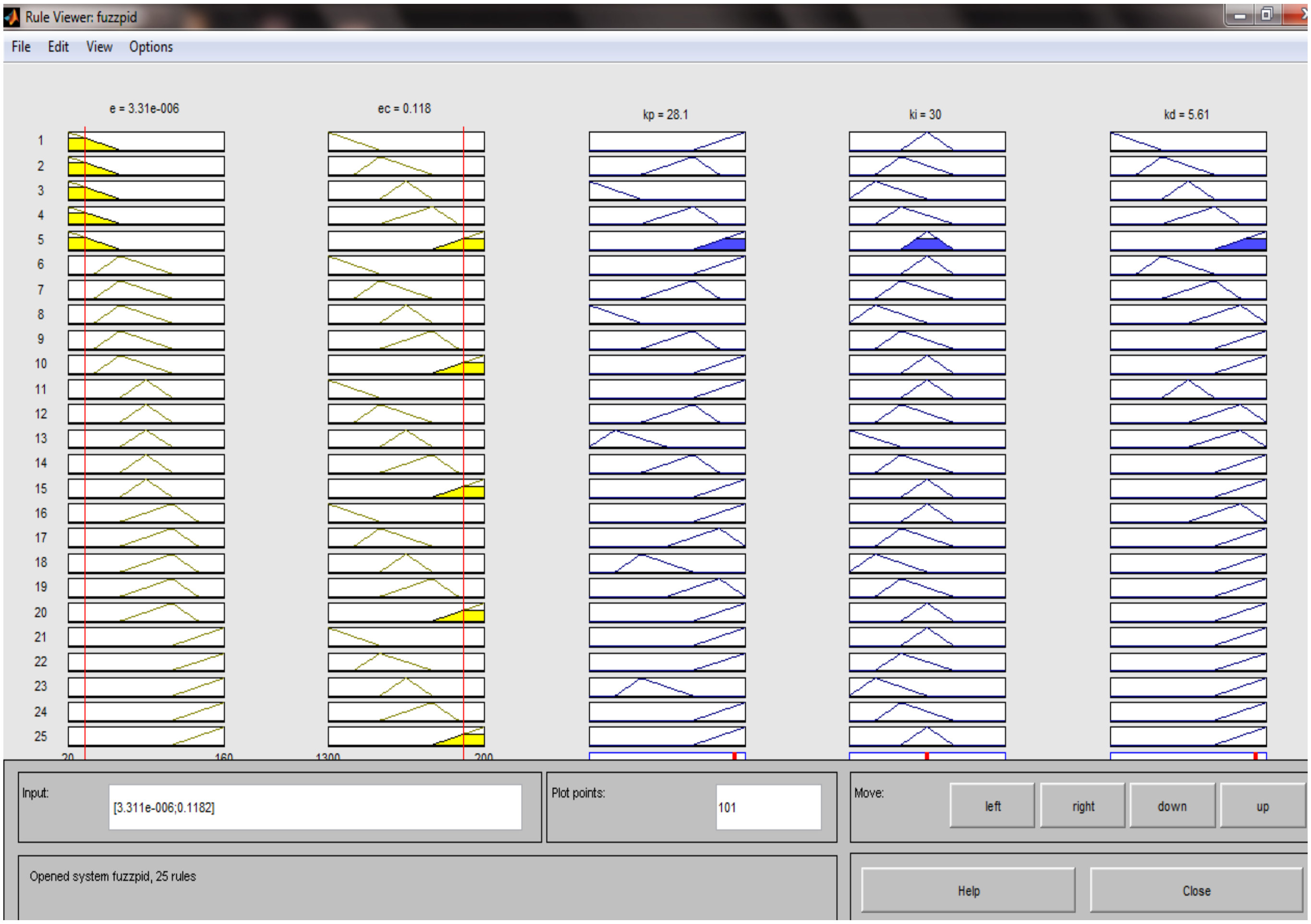


Figure 20: Rule viewer

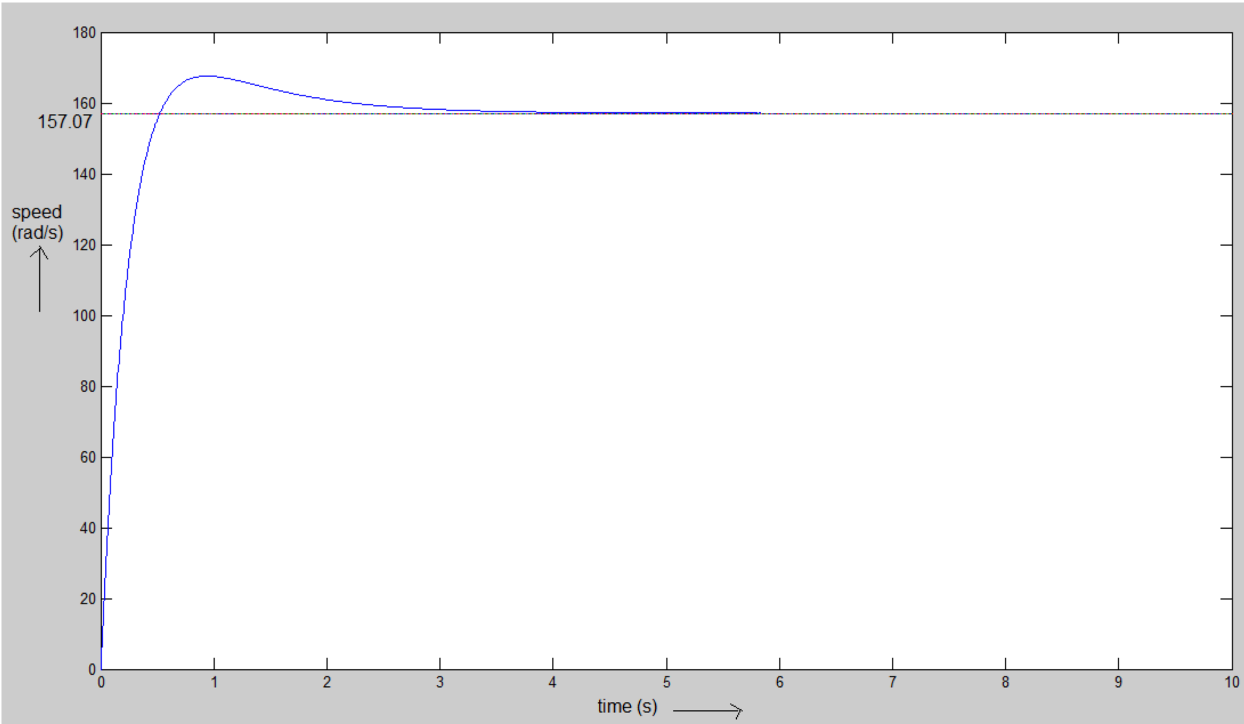


Figure 21: Speed Vs time response of fuzzy tuned PID controlled DC motor

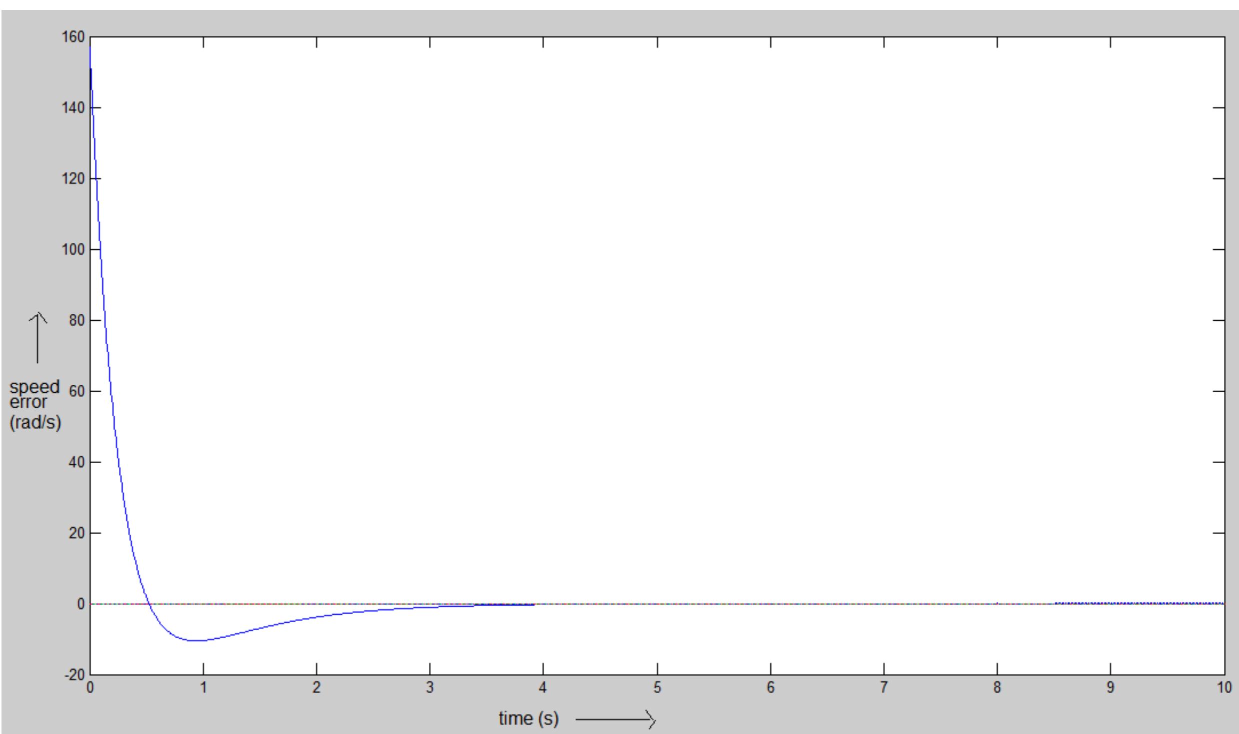


Figure22: Error Vs time response of fuzzy tuned PID controlled DC motor

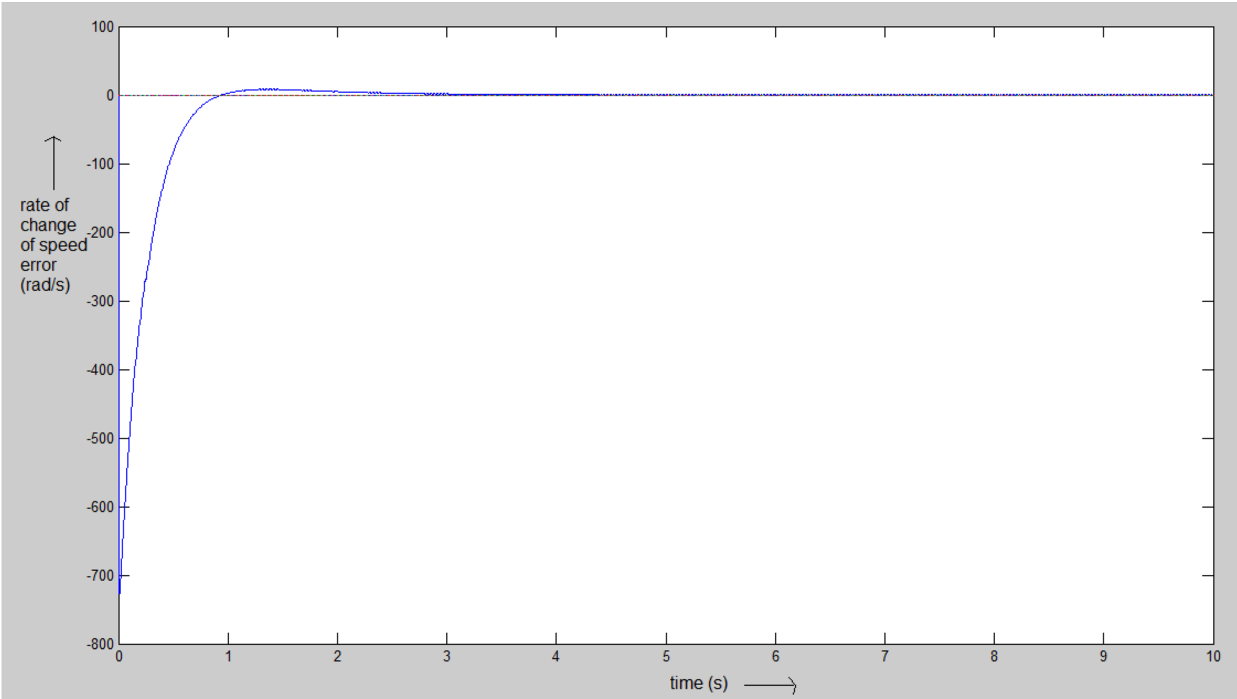


Figure 23: Change of speed Vs time response of fuzzy tuned PID controlled DC motor

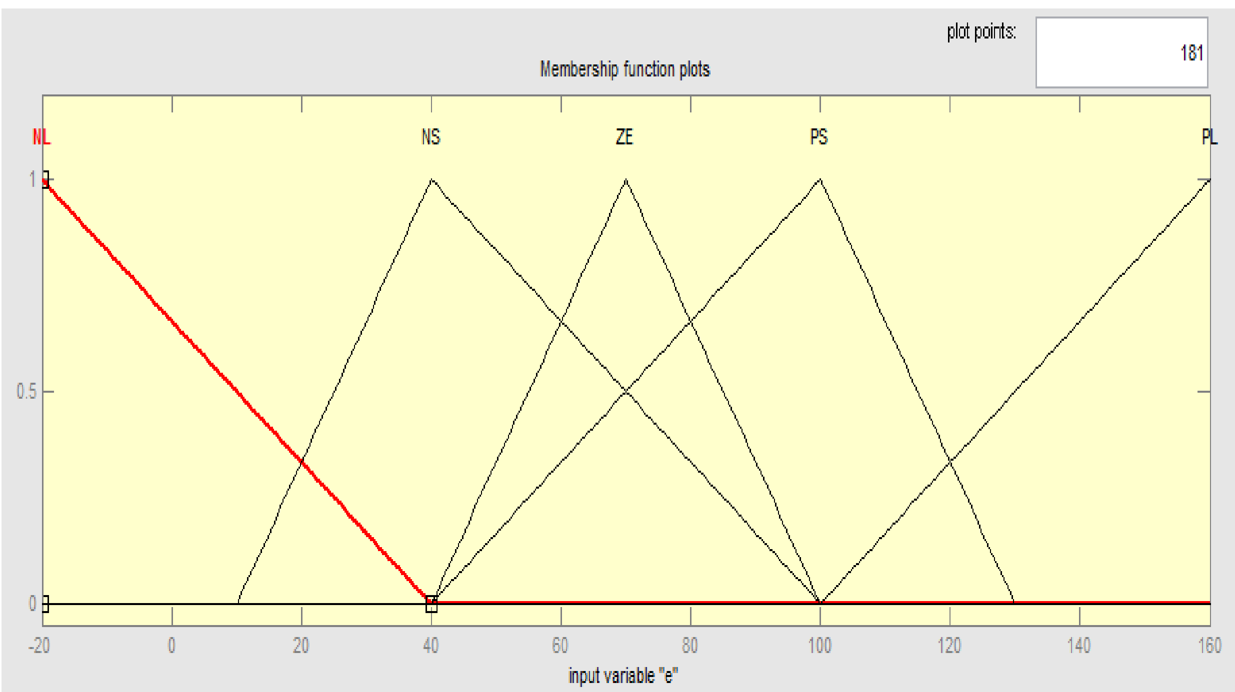


Figure 24: Membership function for input variable 'e'

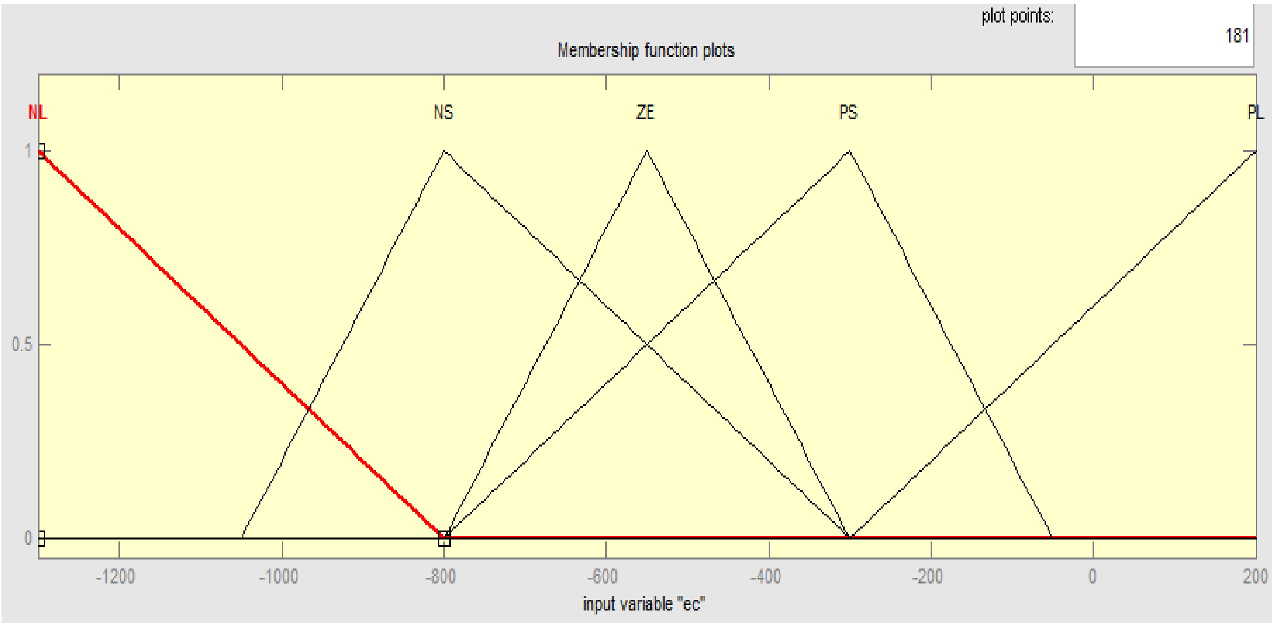


Figure25: Membership function for input variable ‘de’

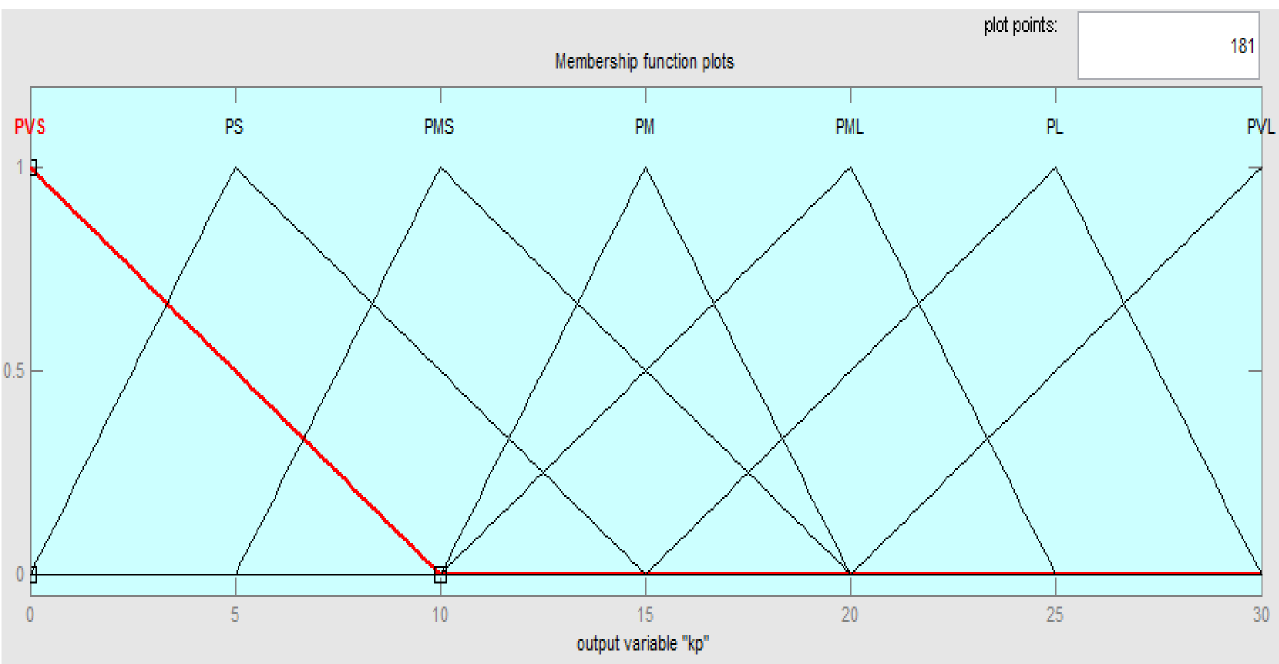


Figure 26: Membership function for output variable ‘K_P’

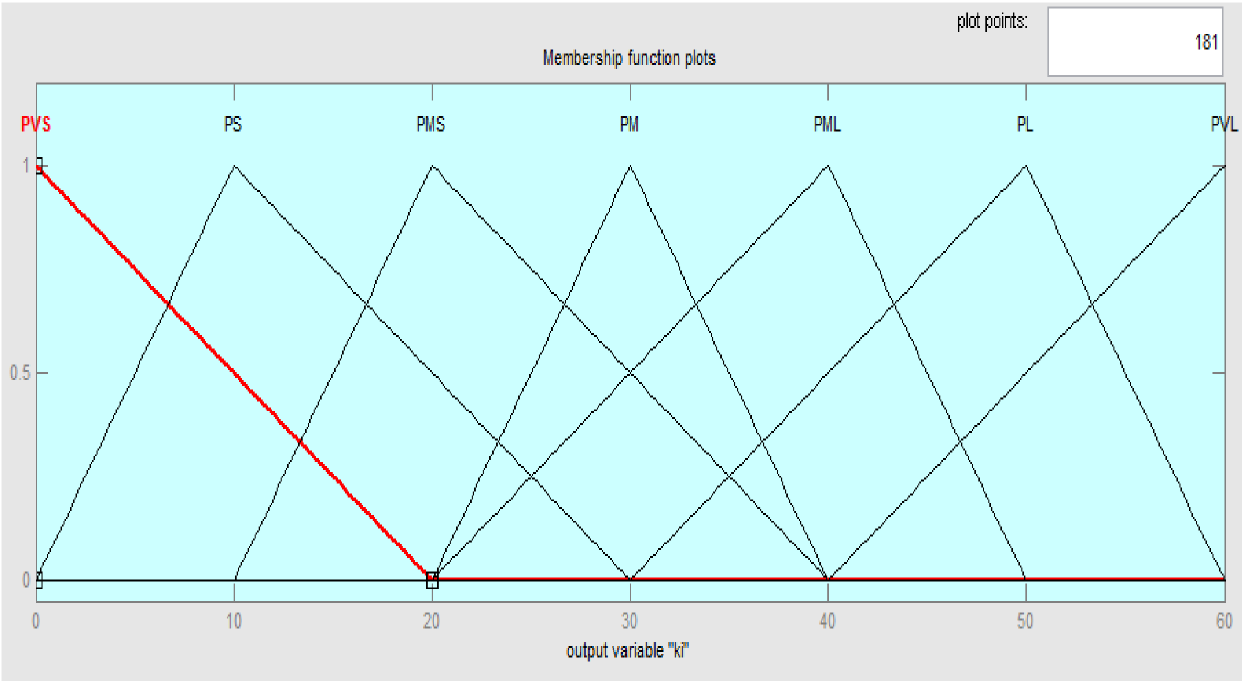


Figure27: Membership function for output variable ‘K_I’

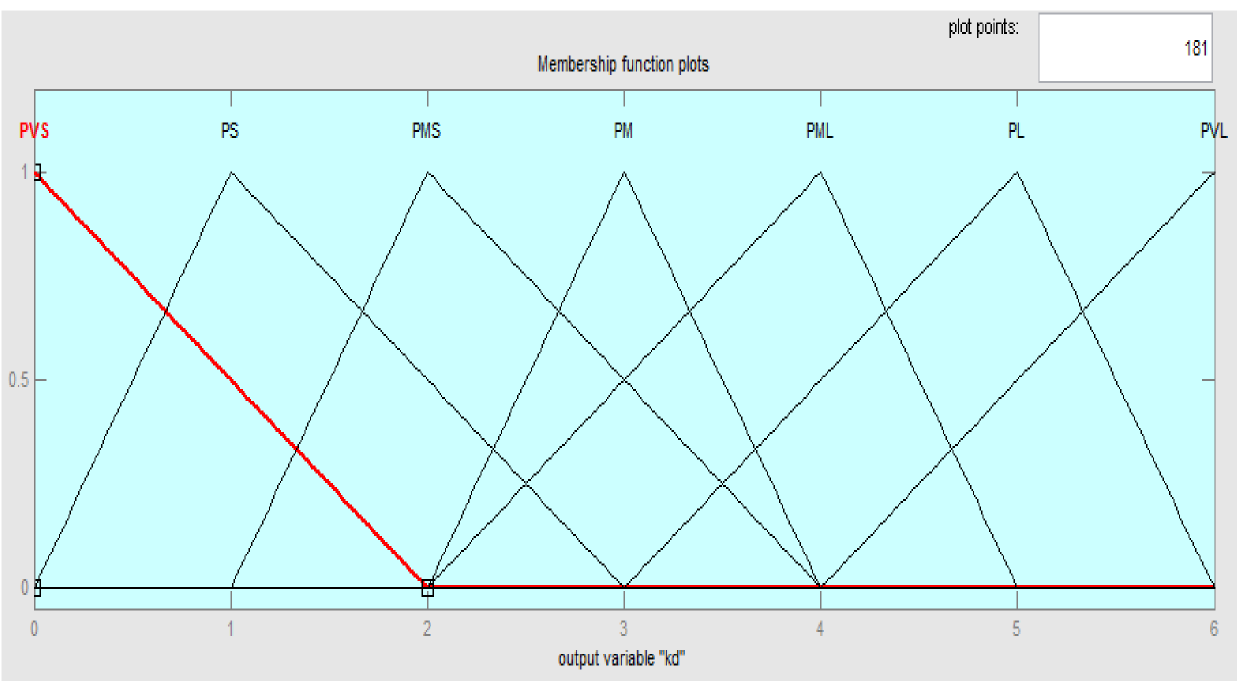


Figure28: Membership function for output variable ‘K_D’

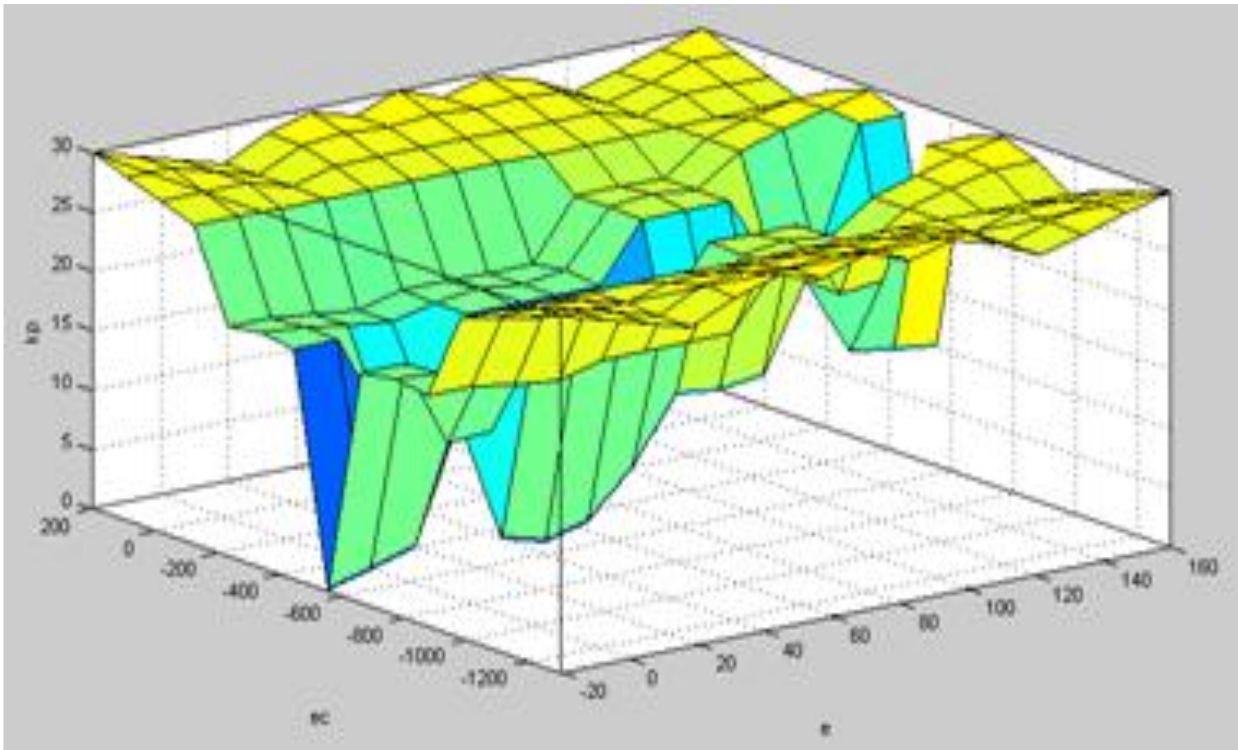


Figure 29: Rule surface viewer of ‘K_P’

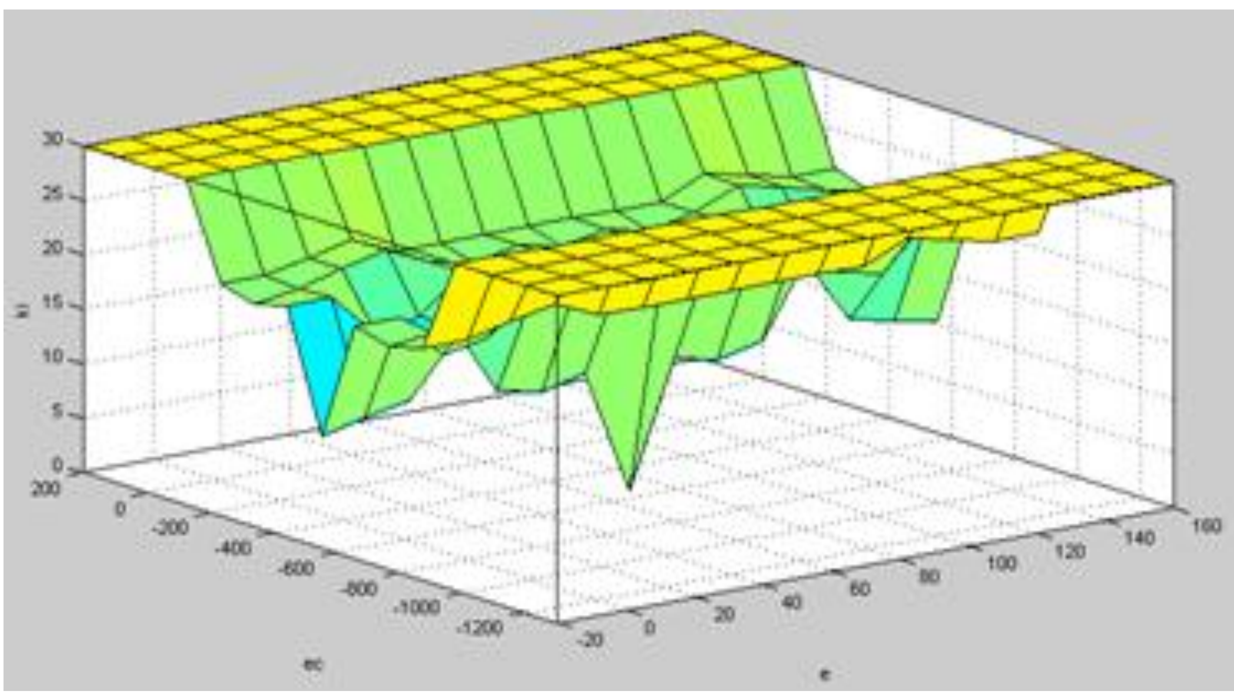


Figure 30: Rule surface viewer of ‘K_I’

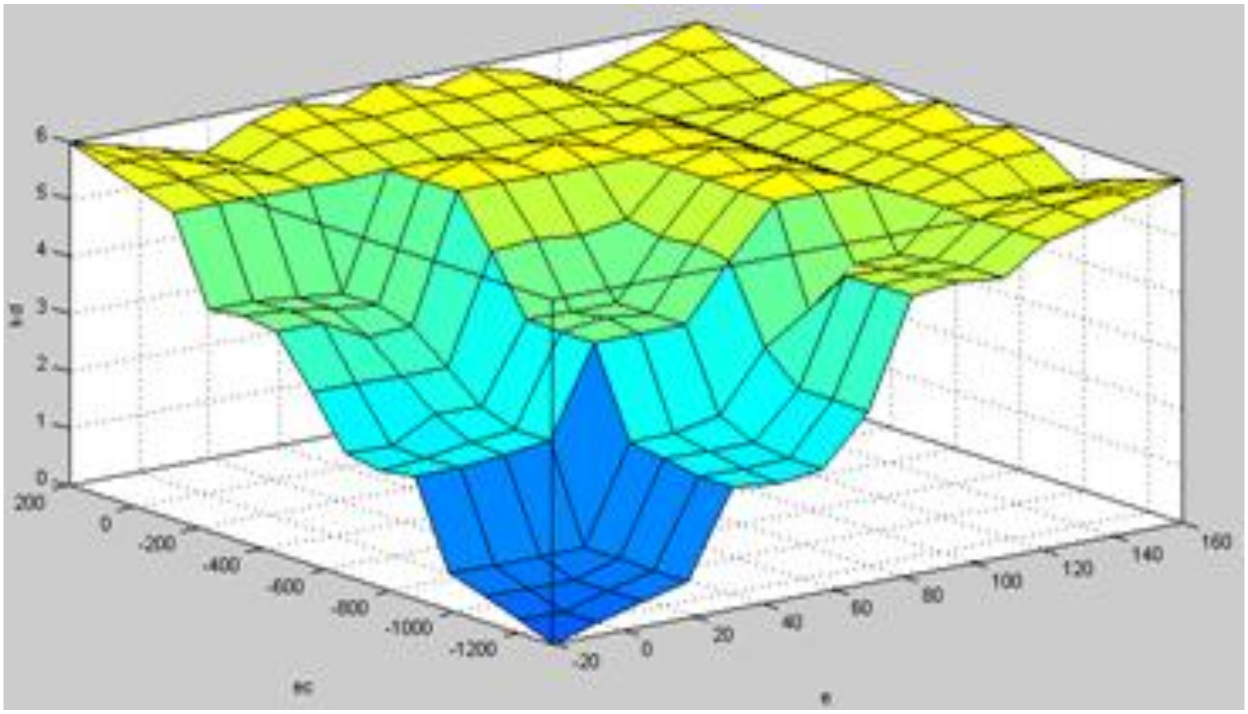


Figure 31: Rule surface viewer of ‘K_D’

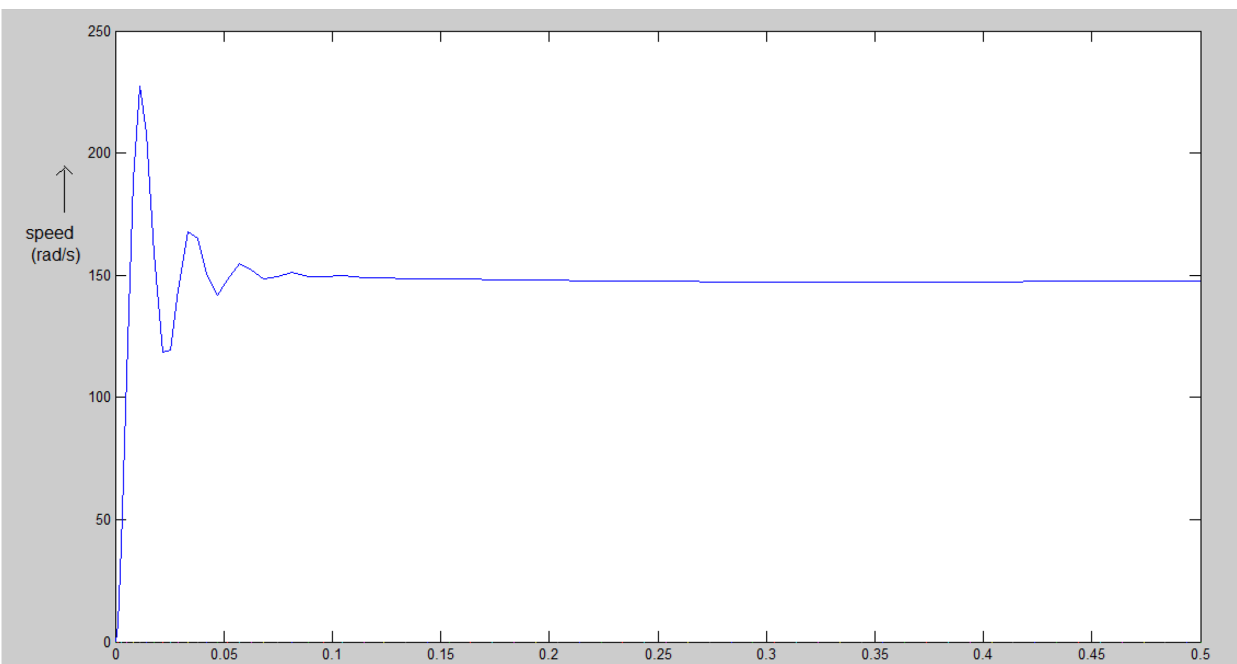


Figure 32: Speed Vs time response of PID controlled DC motor

Chapter 7

Conclusion

7.1:Comparision between self tuned fuzzy PID and conventional PID controller

- Self-tuned tuning PID controller is less compared to conventional PID controller.
- The three parameters "K_P", "K_I", "K_D" of conventional PID control need to be constantly adjust adjusted online in order to achieve better control performance. Fuzzy self-tuning PID parameters controller can automatically adjust PID parameters in accordance with the speed error and the rate of speed error-change,so it has better self-adaptive capacity fuzzy PID parameter controller has smaller overshoot and less rising and settling time than conventional PID controller and has better dynamic response properties and steady-state properties.Steady state error in case of self tuned fuuzy PID is less compared to conventional PID controller.

7.2:Discussion

In this project we have studied about different metod for speed control of DC motor. The steady state operation and its various torque-speeds, torque-current characteristics of DC motor are studied. We have also studied basic definition and terminology of fuzzy logic and fuzzy set. This project introduces a design method of two inputs and three outputs self-tuning fuzzy PID controller and make use of MATLAB fuzzy toolbox to design fuzzy controller.The fuzzy controller adjusted the proportional, integral and derivate (K_P, K_I, K_D) gains of the PID controller according to speed error and change in speed error .From the simulation results it is concluded that ,compared with the conventional PID controller, self-tuning PID controller has a better perfomance in both transient and steady state response.The self tunning FLC has better dynamic response curve, shorter response time, small overshoot, small steady state error (SSE),high steady precision compared to the conventional PID controller.

7.3: Future scope

MATLAB simulation for speed control of separately excited 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).

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