الاية

قال تعالي:

بسم الله الرحمن الرحيم

﴿......وإنا أو إياكم لعلى هدى أو في ضلال مبين﴾

صدق الله العظيم

سورة سبأ   الاية 24

DEDICATION

I have a great pleasure, to dedicate this work to the soul of my parents, who offered me love, support and encouragement.

Also to my brothers, sistersand friends

ACKNOWLEDGMENT

I would like to express my deepest gratitude to my supervisors **Dr Awadalla Taifour Ali** for his support, valuable advice and guidance throughout thiswork.He gave a great effort for connection of necessaryconcepts to complete this search, I extend to him our deepest thanks and appreciation, and ask Allah to bless and guide him.

I extend my thanks to the staff of the school of Electrical Engineering and to my friends for their concern, guidance and moral support.

ABSTRACT

The aim of adaptive control is to adjust unknown or changing manipulated variables. This is achieved by either changing adjustable parameters in the controller in order to minimize error, or by using the plant parameters to estimates the change in controlsignal. There are many different approaches to adaptive control such as self-tuning and Model Reference Adaptive Control (MRAC). Among adaptive control methods the MRAC has earned wide respect since its effectiveness is sufficiently illustrated in real time applications.

The main objective of this study is to design a speed control system for a DC Motor by using Model Reference Fuzzy Adaptive Control (MRFAC). The objective of the MRFAC is to change the rules definition in the direct Fuzzy Logic Controller (FLC) and rule base table according to the comparison between the reference model output signal and system output. The MRFAC is composed by the fuzzy inverse model and a knowledge base modifier. Because of its improved algorithm, the MRFAC has fast learning features and good tracking characteristics even under severe variations of system parameters. The learning mechanism observes the plant outputs and adjusts the rules in a direct fuzzy controller, so that the overall system behaves like a reference model, which characterizes the desired behavior.

In the proposed scheme, the error and error change measured between the motor speed and output of the reference model are applied to the MRFAC. The MRFAC is applied to a separately excited DC motor. High performances and robustness have been achieved by using the MRFAC. This is illustrated by simulation results and comparisons with other controllers such as PIDcontroller,conventional MRACand PD fuzzy controller.

مستخلص

الهدف من التحكم التكيفي هو ضبط او تغير المعاملات غير المعروفة بالنسبه النظام .ويتحقق ذلك اما عن طريق تغير معاملات المتحكم وذلك لتقليل الخطأ او عن طريق استخدام تقدير معاملات النظام لتغير اشاره المتحكم ، لذا هنالك عده طرق للتحكم التكيفي مثل التحكم الذاتي و التحكم التكيفي المرجعي النموذجي . من بين طرق التحكم التكيفي ،اكتسب التحكم التكيفي المرجعي النموذجي اعتبارا كبيرا وذلك نسبه لفعاليته في تطبيقات الزمن الحقيقي.

الهدف الرئيسي من هذا البحث هو تصميم نظام للتحكم في سرعة محرك التيار المستمر باستخدام التحكم التكيفي المرجعي النموذجيمع وحدة تحكم غامض (MRFAC).

الهدف من التحكم التكيفي الغامض مع المرجعي النموذجي (MRFAC) هو تغيير تعريف القواعد المعرفه في وحدة تحكم المنطق الغامض (FLC) وكذلك قواعد الجدول الأساسي وفقا للمقارنة بين خرج النموذج المرجعي وخرج النظام . ال (MRFAC) ويتكون من نموذج معكوس غامض ومعدل قاعدة المعرفة. بسبب تحسن الخوارزمية، و(MRFAC) يمتلك مميزات وخصائص تتبع جيدة التعلم حتى في ظل الاختلافات الشديدة من معاملات النظام. آلية التعلم تلاحظ مخرجات النظام وتضبط القواعد في اتجاه وحدة التحكم الغامض مباشرة، حتى أن النظام العام يتصرف وكأنه النموذج المرجعي، الذي يتميز بالسلوك المطلوب.في المخطط المقترح، تم قياس الخطأ و التغير في الخطأ بين سرعة المحرك وخرج النموذج المرجعي بحيث يتم تطبيقه علي (MRFAC).وال (MRFAC) تم تطبيقهعلى محرك تيار مستمر منفصل الإثارة. وقد تم تحقيق الأداء العالي والمتانة باستخدام ال (MRFAC). سوف يتضح ذلك من خلال نتائج المحاكاه والمقارنه مع المتحكمات الاخري مثل التحكم التناسبي التكاملي التفاضلي (PID) ، المتحكم التكيفي المرجعي النموذجي والتحكم الغامض .

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ABBREVIATIONS

DC	Direct Current

FIS	Fuzzy Inference System
FLC	Fuzzy Logic Controller
MIT	Massachusetts Institute Technology
MRAC	Model Reference Adaptive Control
MRLAC	Model Reference Linear Adaptive Controller
MRFAC	Model Reference Fuzzy Adaptive Controller
PID	Proportional–Integral–Derivative
PD	Proportional – Derivative
PM	Permanent-magnet

CHAPTER ONE

INTRODUCTION

1.1General

Almost every mechanical movement that seen around is accomplished by an electric motor. Electric machines are a means of converting energy. Motors take electrical energy and produce mechanical energy. Electric motors are used to power hundreds of devices used in everyday life. Motors come in various sizes, huge motors that can take loads of thousands of horsepower are typically used in industry. Some examples of large motor applications include elevators, electric trains, hoists, and heavy metal rolling mills. Examples of small motor applications include motors used in automobiles, robots, hand power tools and food blenders. Micro-machines are electric machines with parts the size of red blood cells, and find many applications in medicine[1].

DC motors are extensively used in industry and there are different methods for controlling the speeds of these motors. According to the structure of the DC motor, these methods act by changing the armature resistance, the field resistance or the armature voltage.

Changing the armature voltage and field circuit increases losses in DC motors, so the best method is changing the armature voltage[2]. There are different methods for controlling the DC motor, which are divided in two general categories: classic methods such as using Proportional–Integral–Derivative PID controller and pulse width modulation and intelligent methods such as neural networks, genetic algorithms, fuzzy control and model reference fuzzy control .Model Reference Adaptive Control (MRAC) is one of the ways to deal with the uncertainties of plants. Industrial drives are usually subject to uncertainties in many ways and (MRAC) such drives are quite capable of dealing with these problems. Model Reference Linear Adaptive Controller

(MRLAC) of DC drives subjected to disturbance and uncertainties avoids all these complexities.

1.2 Objective of Research

1- To design a speed control system for DC motor using MRAC with model reference fuzzy adaptive controller (MRFAC)
2- To investigate the performance of the drive upon load and disturbances.
3- To compare the performance of model reference fuzzy adaptive scheme against conventional MRAC

1.3 Methodology

The convention technique such as PID, PD fuzzy and MRAC are replaced by MRFAC.The performance of the drive system formed a set of test conditions with MRFAC, and tested for load disturbance along with reference model. Also, a model of MRFAC to control speed of DC motor and MRAC is constructed. The input to the fuzzy controller is selected as error e (t) between the DC drive and reference model speed, and change of error (Ce), the membership function are used for input variable. All the steps are carried-out by using MATLAB SIMULINK program, then the performance of the model reference adaptive fuzzy controller is compared to convention MRAC

1.4Statement of Problem

Industrial drives are usually subject to disturbances and uncertainties in many ways .The Model Reference Adaptive Control (MRAC) speed control systems do not achieve consistent satisfactory performance over wide range of speed demand, especially at low speed and there is no defined rule to guide designers to choose the adaptation gains. Theconvention model reference adaptive system requires selection of the best length for a period of adjustment, depends on the values of the command signal .Also it does not guarantee the stability of the nominal system and requires long time period for the system in order to follow that quiteclosely.

1.5 Layout

This thesis consists of five Chapters; Chapter One gives an introduction, reason and motivationof work. Chapter Two outline briefly the principle and theory of separately excited DC motor, principle of PID controller,MRAC, Fuzzy logic, and MRFAC.Chapter Three deal with the mathematical and simulation model of a DC motor, also focuses on the methodology and the implementation of various control algorithms such as PID, PD fuzzy, MRAC and MRFAC for the separately excited DC motor.Chapter Four presents the results and discussions. Finally Chapter Five provides the conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 DC Motor

Electric machines are a means of converting energy. Motors take electrical energy and produce mechanical energy. Electric motors are used to power hundreds of devices used in everyday life. Electric motors are broadly classified into two different categories: DC (Direct Current) and AC (Alternating Current). Within these categories are numerous types, each offering unique abilities that suit them well for specific applications.

In most cases, regardless of type, electric motors consist of a stator (stationary field) and a rotor (the rotating field or armature) and operate through the interaction of magnetic flux and electric current to produce rotational speed and torque. DC motors are distinguished by their ability to operate from direct current. There are different kinds of DC motors, but they all work on the same principles. In this chapter their basic principle of operation and their characteristics will be studied [3].

2.1.1 DC motor construction

A DC motor is a device that deals the conversion of electrical energy to mechanical energy and this is essentially brought about by two major parts required for the construction of dc motor, namely: Stator – the static part that houses the field windings and receives the supply and,Rotor the rotating part that brings about the mechanical rotations.

Other than that there are several subsidiary parts namely: yoke of DC motor**,**poles of DC motor**,** field winding of DC motor**,** armature winding of DC motor, Commutator of

DC motor and brushes of DC motor. All these parts put together configures the total construction of a DC motor as shown in Figure (2.1).

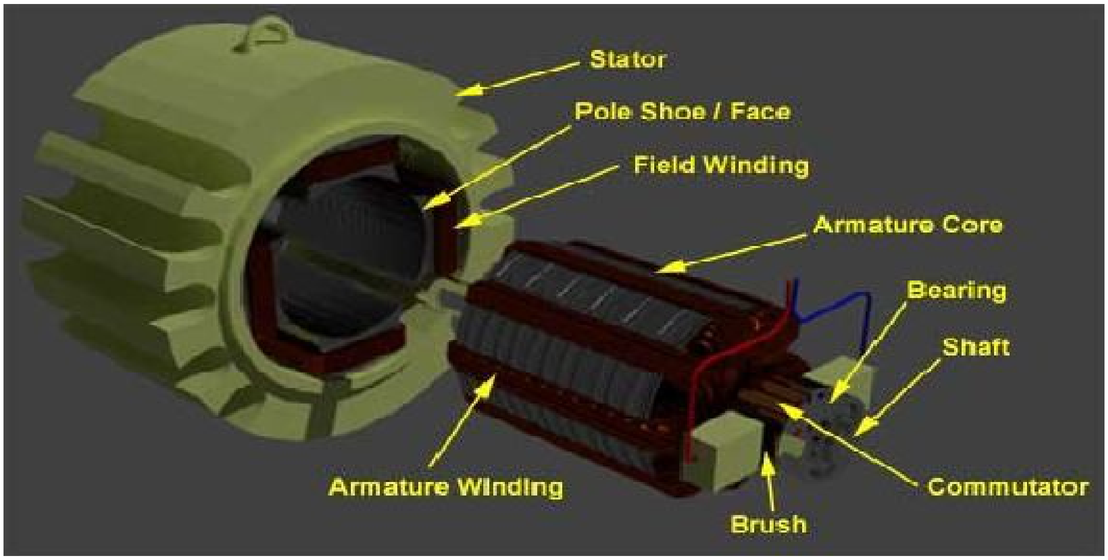

Figure 2.1: Construction of DC motor

2.1.2 DC motor equivalent circuit

The schematic diagram for a DC motor is shown in Figure (2.2). A DC motor has two distinct circuits: Field circuit and armature circuit. The input is electrical power and the output is mechanical power. In this equivalent circuit**,** the field winding is supplied from a separate DC voltage source of voltageV_f,$R_f$and L_f represent the resistance and inductance of the field winding. The current I_f produced in the winding establishes the magnetic field necessary for motor operation. In the armature (rotor) circuit, $e_a$is the voltage applied across the motor terminals, I_a is the current flowing in the armature circuit, $R_a$is the resistance of the armature winding, and V_a is the total voltage induced in the armature [4] .

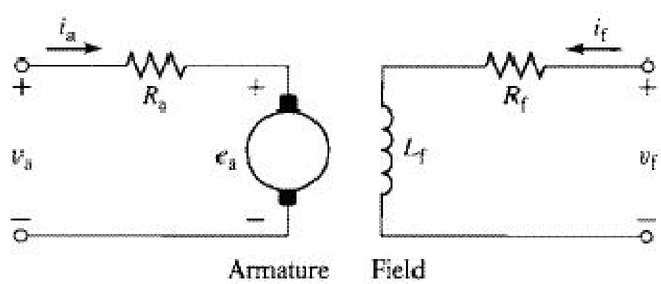

Figure 2.2: DC motor equivalent circuit

2.1.3 DC motor classification

DC machines can be classified according to the electrical connections of the armature winding and the field windings. The different ways in which these windings are connected lead to machines operating with different characteristics. The field winding can be either self-excited or separately-excited, that is, the terminals of the winding can be connected across the input voltage terminals or fed from a separate voltage source. Further, in self-excited motors, the field winding can be connected either in series or in parallel with the armature winding. These different types of connections give rise to very different types of machines as have been studied in this chapter. Figure (2.3) shows types of DC motor.

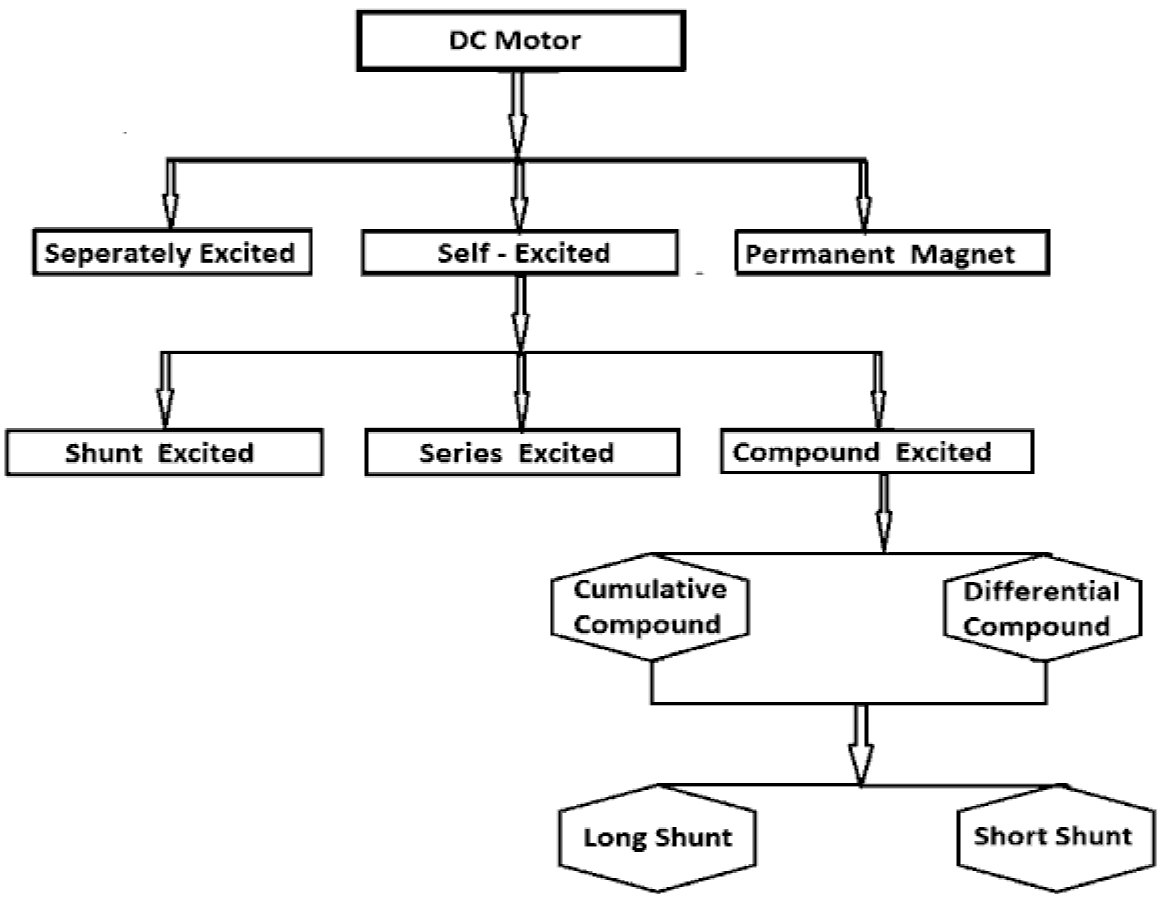

Figure 2.3: Typesof DC motor

i - Separately excited DC motor

As the name suggests, in case of a separately excited DC motor the supply is given separately to the field and armature windings. The main distinguishing fact in these types of dc motor is that, the armature current does not flow through the field windings, as the field winding is energized from a separate external source of DC current as shown in the Figure (2.4). From the torque equation of DC motor we know that

$$T_g = K_a \text{Ø} I_a \qquad (2.1)$$

So the torque in this case can be varied by varying field flux φ, independent of the armature current I_a .

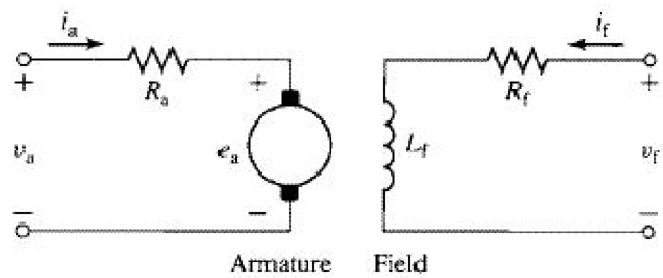

Figure 2.4:separately excited DC motor

ii - Permanent magnet DC motor

The permanent magnet of DC motor consists of an armature winding as in case of a usual motor, but does not necessarily contain the field windings. The construction of these types of DC motor are such that, radially magnetized permanent magnets are mounted on the inner periphery of the stator core to produce the field flux. The rotor on the other hand has a conventional DC armature with commutator segments and brushes. The diagrammatic representation of a permanent magnet DC motor is given in the Figure (2.5).

The torque equation of DC motor suggests

$$T_g = K_a \text{Ø} I_a \qquad (2.2)$$

Here Ø is always constant, as permanent magnets of required flux density are chosen at the time of construction and can't be changed there after.

For a permanent magnet DC motor

$$T_g = K_{a1} I_a \qquad (2.3)$$

Where K_{a1}= K_a Ø which is another constant. In this case the torque of DC motor can only be changed by controlling armature supply.

iii- Self excited DC motor

In case of self-excited DC motor, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding, and on this basis it's further classified as: - a – Shunt wound DC motor. b- Series wound DC motor. c – Compound wound DC motor.

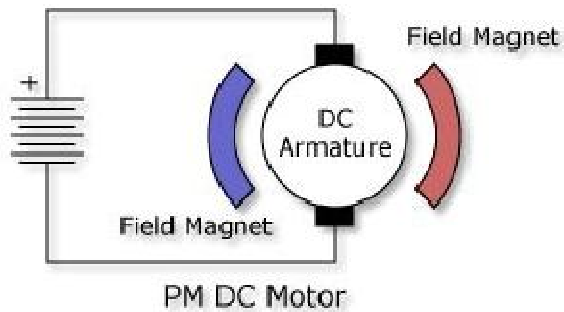

Figure 2.5:Permanent magnet DC motor

- **Shunt Wound DC Motor**

In case of a shunt wound DC motor or more specifically shunt wound self-excited DC motor, the field windings are exposed to the entire terminal voltage as they are connected in parallel to the armature winding .To understand the characteristic of these types of DC motor, let's consider the basic voltage equation given by

$$E = E_b + I_a R_a \quad (2.4)$$

Where E, Eb, I_a , Ra are the supply voltage, back emf, armature current and armature resistance respectively.

Now

$$E_b = K_a Ø \, \omega \quad (2.5)$$

Since back emf increases with flux φ and angular speed ω .Now substituting E_b from equation

(2.4) to equation (2.5).

E = $K_a Ø$ ω+$I_a R_a$(2.6)

ω = $E - I_a R_a$ / $K_a Ø$ (2.7)

The torque equation of a DC motor resembles

$T_g = K_a \, \emptyset I_a$(2.8)

This is similar to the equation of a straight line, and graphically it representing the torque speed characteristic of a shunt wound self-excited DC motor as:

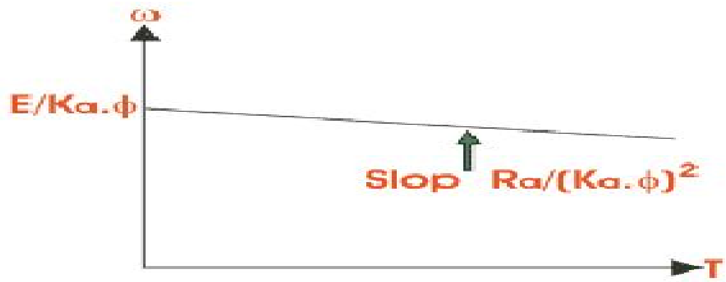

Figure 2.6: torque speed characteristic of a shunt wound self-excited DC motor

The shunt wound DC motor is a constant speed motor, as the speed does not vary here with the variation of mechanical load on the output.

- **Series wound DC motor**

In case of a series wound self-excited DC motor or simply series wound DC motor, the entire armature current flows through the field winding as it's connected in series to the armature winding. The series wound self-excited DC motor is diagrammatically in the Figure (2.7).

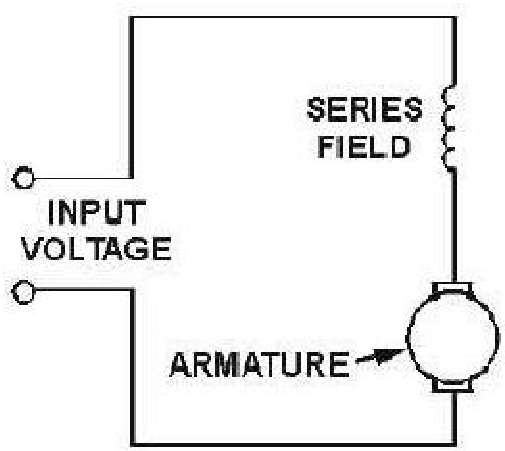

Figure 2.7:Series excited DC motor

Now to determine the torque speed characteristic of these types of DC motor, let's get to the torque speed equation. From the circuit diagram it be can see that the voltage equation gets modified to

$$E = E_b + I_a(R_a + R_s) \quad (2.9)$$

Whereas back emf remains E_b = $k_a\varphi\omega$, neglecting saturation,

$$\text{Ø} = K_1 I_f = K_1 I_a \quad (2.10)$$

Since field current = armature current

There for,

$$E_b = K_a K_1 I_a \omega = K_s I_a \omega \quad (2.11)$$

From equation (2.9) & (2.11)

$$\omega = \frac{E}{I_a K_s} - \frac{R_s + R_a}{K_s} \quad (2.12)$$

From this equation the torque speed characteristics is obtained as shown in Figure (2.8).

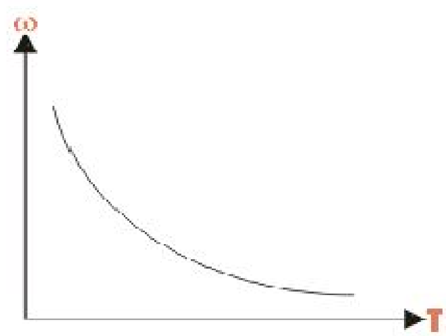

Figure 2.8: the torque speed characteristic

- **Compound wound DC motor**

The compound excitation characteristic in a DC motor can be obtained by combining the operational characteristic of both the shunt and series excited DC motor. The compound wound self-excited DC motor or simply compound wound DC motoressentially contains the field winding connected both in series and in parallel to the armature winding as shown in the Figure (2.9). The excitation of compound wound DC motor can be of two types depending on the nature of compounding.

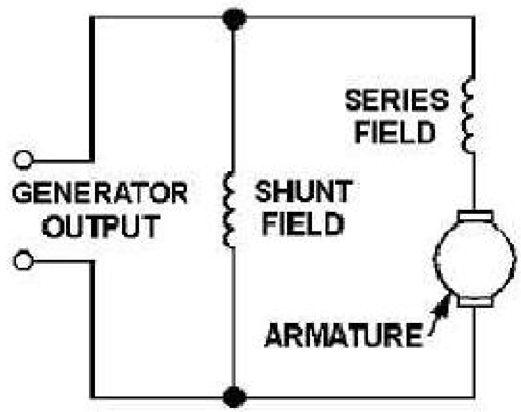

Figure 2.9: Compound wound DC motor

- **Cumulative compound DC motor**

When the shunt field flux assists the main field flux, produced by the main field connected in series to the armature winding then it's called cumulative compound dc motor.

$$\varnothing_{total} = \varnothing_{series} + \varnothing_{shunt} \tag{2.13}$$

- **Differential compound DC motor**

In case of a differentially compounded self-excited DC motor i.e. differential compound DC motor, the arrangement of shunt and series winding is such that the field flux produced by the shunt field winding diminishes the effect of flux by the main series field winding.

$$\varnothing_{total} = \varnothing_{series} - \varnothing_{shunt} \tag{2.14}$$

The net flux produced in this case is lesser than the original flux and hence does not find much of a practical application.

The compounding characteristic of the self-excited DC motor is shown in the Figure (2.10). Both the cumulative compound and differential compound DC motor can either be of short shunt or long shunt type depending on the nature of arrangement.

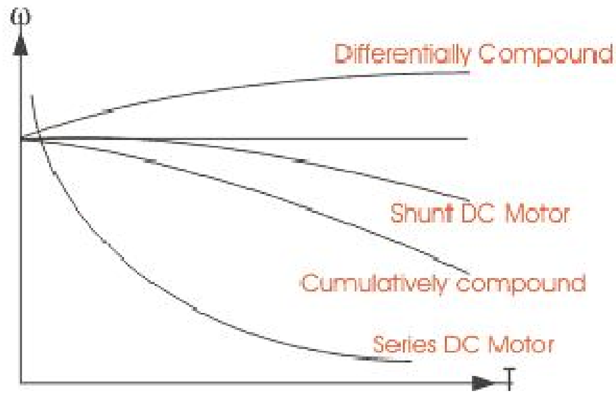

Figure 2.10:the compounding characteristic of the self-excited DC motor

2.2PID Controller

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. PID (proportional integral derivative) control is one of the earlier control strategies. Its early implementation was in pneumatic devices, followed by vacuum and solid state Analog electronics, before arriving at today's digital implementation of microprocessors. The microprocessor has had a dramatic influence on the PID controller. Practically all PID controllers made today are based on microprocessors [5].As the name suggests, the PID algorithm consists of three basic modes, the Proportional mode, the Integral and the Derivative modes.

2.2.1 P Controller

P controller is mostly used in first order processes with single energy storage to stabilize the unstable process. The main usage of the P controller is to decrease the steady state error of the system. As the proportional gain factor K increases, the steady state error of the system decreases. However, despite the reduction, P control can never manage to eliminate the steady state error of the system. As increased the proportional gain, it provides smaller amplitude and phase margin, faster dynamics satisfying wider frequency band and larger sensitivity to the noise. We can use this controller only when our system is tolerable to a constant steady state error. In addition, it can be easily concluded that applying P controller decreases the rise time and after a certain value of reduction on the steady state error, increasing K only leads to overshoot of the system response. P - Control also causes oscillation if sufficiently aggressive in the presence of lags and/or dead time.

The more lags (higher order), the more problem it leads. Plus, it directly amplifies process noise.

2.2.2 P-I Controller

P-I controller is mainly used to eliminate the steady state error resulting from P controller. However, in terms of the speed response and overall stability of the system, it has a negative impact. This controller is mostly used in areas where speed of the system is not an issue. Since P-I controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations. If applied, any amount of integral guarantees set point overshoot.

2.2.3 P-D Controller

The aim of using P-D controller is to increase the stability of the system by improving control since it has an ability to predict the future error of the system response. In order to avoid effects of the sudden change in the value of the error signal, D mode is designed to be proportional to the change of the output variable to prevent the sudden changes occurring in the control output resulting from sudden changes in the error signal. In addition D directly amplifies process noise therefore D-only control is not used.

2.2.4 P-I-D Controller

P-I-D controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the P-I-D controller is that it can be used with higher order processes including more than single energystorage.

2.2.5PID Structure

A typical structure of a PID control system is shown in Figure (2.11), where it can be seen that in a PID controller, the error signal e (t) is used to generate the proportional, integral, and derivative actions, with the resulting signals weighted and summed to form the control signal u (t) applied to the plant model. A mathematical description of the PID controller.

$$Gc(t) = K_c\left[e(t) + \frac{1}{T_i}\int e(\tau)\, d\tau + T_d\frac{de(t)}{dt}\right] \quad (2.15)$$

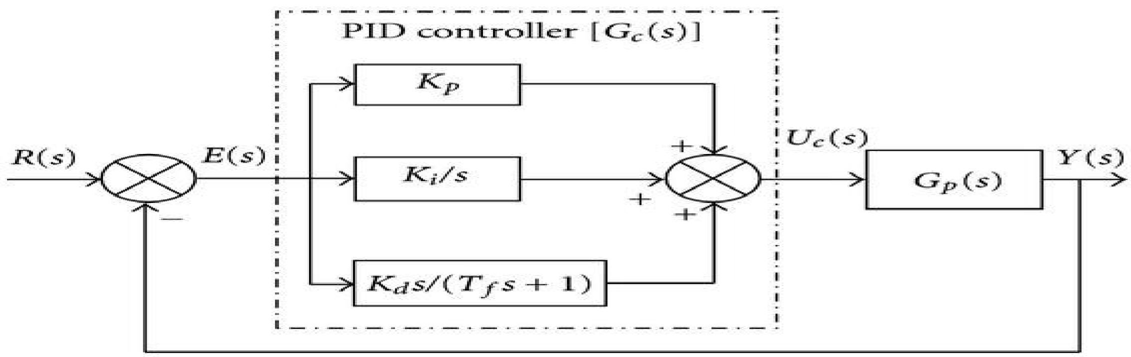

Figure 2.11: PID Structure

In order to minimize rise time, proportional controller Kc gain is used. Introducing an integral controller can eliminate steady-state error, which is responsible for increasing the overshoot. Introducing a derivative Effects of each controller and the characteristics of parameters are summarized in the Table (2.1).

Table 2.1:Characteristics of parametersof PID controllers

Specification	Rise time	Overshoot	Settling time	Steady-state error

Ki	Decrease	Increase	Small Change	Decrease
Kc	Decrease	Increase	Increase	Increase
Kd	Small Change	Decrease	Decrease	Small Change

2.3Model Reference Adaptive Control (MRAC)

A control system is a device that regulates or controls the dynamics of any other plant or process. Adaptive control is one of the widely used control strategies to design advanced control systems for better performance and accuracy. Model Reference Adaptive Control (MRAC) is a direct adaptive strategy with some adjustable controller parameters and an adjusting mechanism to adjust them. As compared to the well-known and simple structured fixed gain PID controllers, adaptive controllers are very effective to handle the unknown parameter variations and environmental changes. An adaptive controller consists of two loops, an outer loop or normal feedback loop and an inner loop or parameter adjustment loop. Model Reference Adaptive Control strategy is used to design the adaptive controller that works on the principle of adjusting the controller parameters so that the output of the actual plant tracks the output of a reference model having the same reference input as shown in the Figure (2.12). [6].

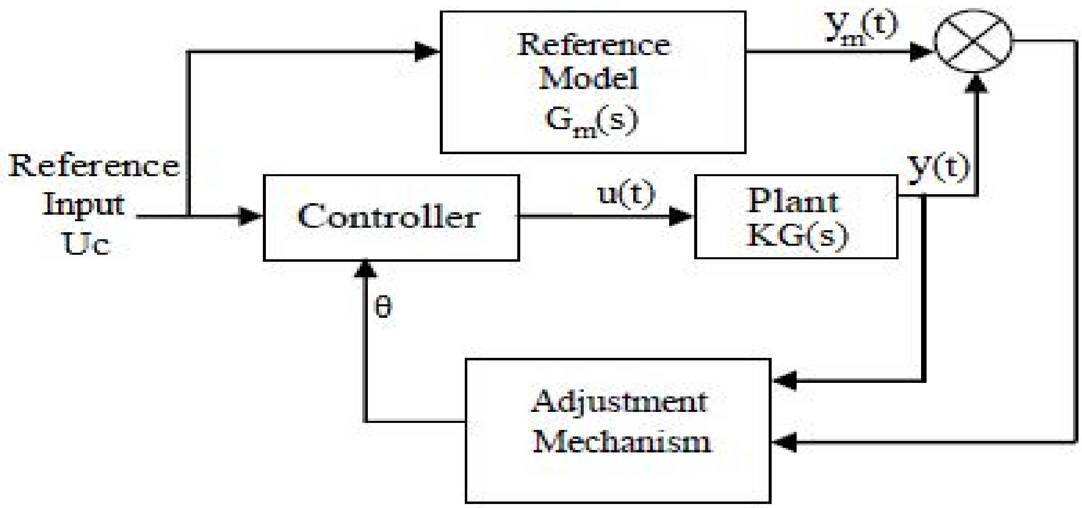

Figure 2:12:Model reference adaptive control structure

2.3.1 Direct and indirect adaptive control

An adaptive controller is formed by combining an on-line parameter estimator, which provides estimates of unknown parameters at each instant, with a control law that is motivated from the known parameter case. The way the parameter estimator, is combined with the control law gives rise to two different approaches. In the first approach, referred to as indirect adaptive control, the plant parameters are estimated on-line and used to calculate the controller parameters.

This approach has also been referred to as explicit adaptive control, because the design is based on an explicit plant model as shown in the Figure (2.13) .[6].

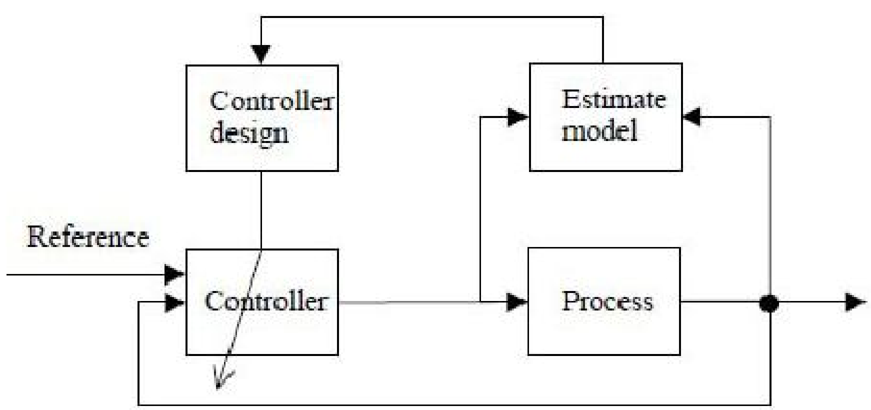

Figure 2.13: Indirect adaptive control

In the second approach, referred to as direct adaptive control, the plant model is parameterized in terms of the controller parameters that are estimated directly without intermediate calculations involving plant parameter estimates. This approach has also been referred to as implicit adaptive control because the design is based on the estimation of an implicit plant model.

2.3.2 The structure of MRAC

Model reference adaptive control (MRAC) is derived from the model following problem or model reference control (MRC) problem. In MRC, a good understanding of the plant and the performance requirements it has to meet allow the designer to come up with a model, referred to as the reference model, that describes the desired I/O properties of the closed-loop plant. The objective of (MRC) is to find the feedback control law that changes the structure and dynamics of the plant so that its I/O properties are exactly the same as those of the reference model. A modal reference adaptive system essentially has an inner loop which forms part of a convention feedback control and an outer loop which adjusts the adaptive control parameters, the basic goal of this type of system is to make the plant behave in the same way as the model.

A block diagram of the system is shown in the Figure (2.14) and the individual blocks are briefly described below.

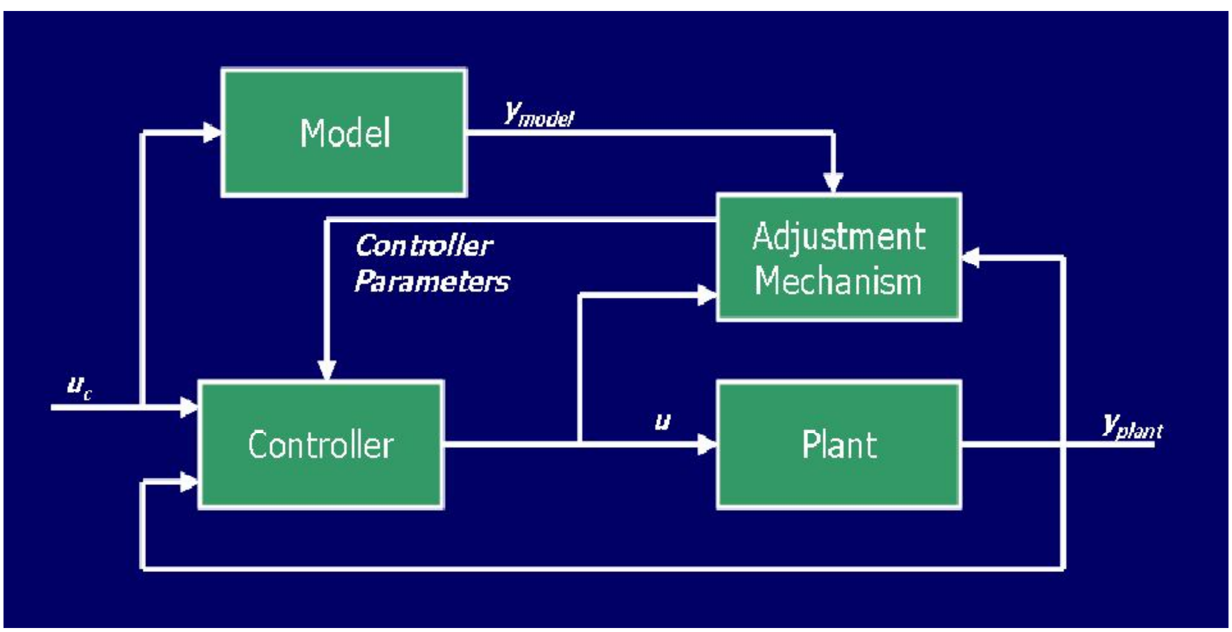

Figure 2.14:the structure of MRAC

i- The plant or process to be controlled.

ii- The model of the plant which provide a reference as to the desired performance that plant should have.

iii- An adjust mechanism provides an output depending on the status of the actual plant output, the plant reference and the status of the model output.

iv- A regulator which actually provides the plant with the reference.

2.4 Fuzzy Logic Control

Fuzzy logic idea is similar to the human being’s feeling and inference process. Unlike classical control strategy, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control. The output of a fuzzy controller is derived from fuzzifications of both inputs and outputs using the associated membership functions.

A crisp input will be converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller is based on its memberships of the different membership functions, which can be considered as a range of inputs [6]. Fuzzy ideas and fuzzy logic are so often utilized in our routine life that nobody even pays attention to them. For instance, to answer some questions in certain surveys, most time one could answer with 'Not Very Satisfied' or 'Quite Satisfied', which are also fuzzy or ambiguous answers. Exactly to what degree is one satisfied or dissatisfied with some service or product for those surveys? These vague answers can only be created and implemented by human beings, but not machines.

Is it possible for a computer to answer those survey questions directly as a human beings did? It is absolutely impossible. Computers can only understand either '0' or '1', and 'HIGH' or 'LOW'. Those data are called crisp or classic data and can be processed by all machines. The idea of fuzzy logic was invented by Professor L. A. Zadeh of the University of California at Berkeley in 1965. This invention was not well recognized until Dr. E. H. Mamdani, who is a professor at London University, applied the fuzzy logic in a practical application to control an automatic steam engine in 1974, which is almost ten years after the fuzzy theory was invented [7].

Then, in 1976, Blue Circle Cement and SIRA in Denmark developed an industrial application to control cement kilns. That system began to operation in 1982. More and more fuzzy implementations have been reported since the 1980s, including those applications in industrial manufacturing, automatic control, automobile production, banks, hospitals, libraries and academic education. Fuzzy logic techniques have been widely applied in all aspects in today’s society. To implement fuzzy logic technique to a real application requires the following three steps:

i- Fuzzification – convert classical data or crisp data into fuzzy data or Membership Functions (MFs)

ii- Fuzzy Inference Process – combine membership functions with the control rules to derive the fuzzy output

iii- Defuzzification – use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application[8]. Figure (2.15) shown the structure diagram of fuzzy logic.

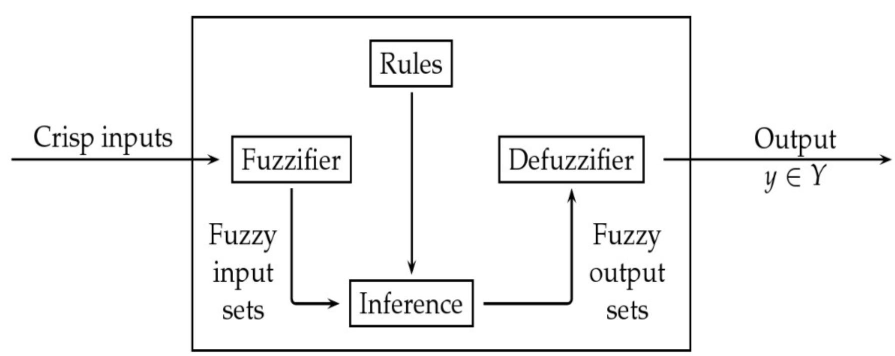

Figure 2.15: Fuzzy structure

2.4.1 Fuzzy sets

The concept of the fuzzy set is only an extension of the concept of a classical or crisp set. The fuzzy set is actually a fundamentally broader set compared with the classical or crisp set. The classical set only considers a limited number of degrees of membership such as ‘0’ or ‘1’, or a range of data with limited degrees of membership. On the other hand the fuzzy set uses a universe of discourse as its base and it considers an infinite number of degrees of membership in a set. In this way, the classical or crisp set can be considered as a subset of the fuzzy set.

2.4.2 Fuzzy sets and operations

As it`s said in previous section, the classical set has a sharp boundary, which means that a member either belongs to that set or does not. Also, this classical set can be mapped to a function with two elements, 0 or 1.

Compared with a classical set, a fuzzy set allows members to have a smooth boundary. In other words, a fuzzy set allows a member to belong to a set to some partial degree.

It is clear that a fuzzy set contains elements which have varying degrees of membership in the set, and this is contrasted with the classical or crisp sets because members of a classical set cannot be members unless their membership is full or complete in that set. A fuzzy set allows a member to have a partial degree of membership and this partial degree membership can be mapped into a function or a universe of membership values.

For example, if A is a fuzzy interval between 5 and 8 and B be a fuzzy number about 4 as shown in the Figure (2.16).

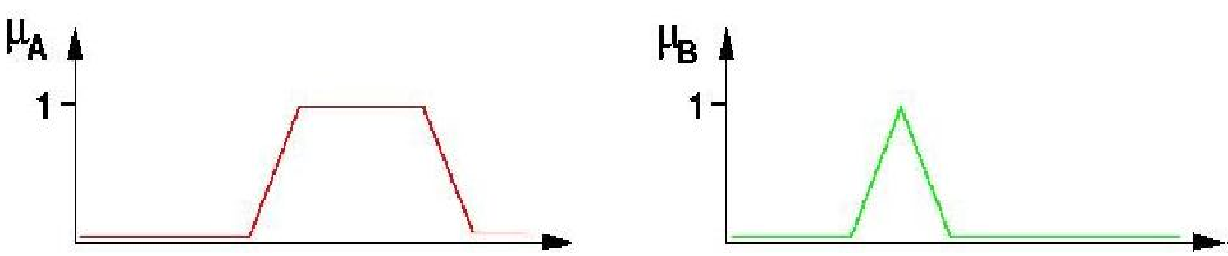

Figure 2.16: Fuzzy sets

In this case, the fuzzy set between 5 and 8 AND about 4 is shown in Figure (2.17).

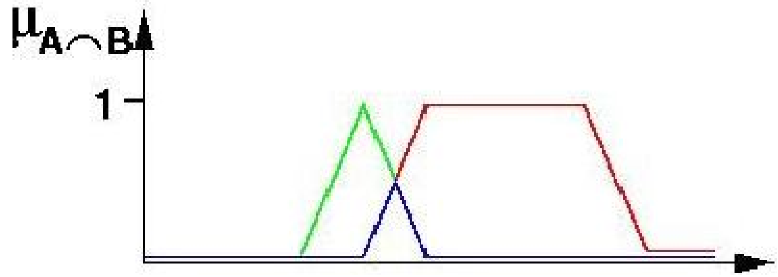

Figure 2.17: Fuzzy AND

Set between 5 and 8 OR about 4 is shown in the figure (2-18).

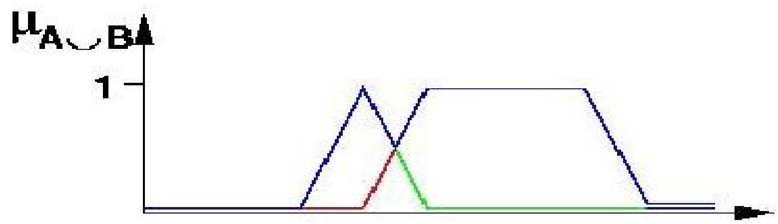

Figure 2.18: Fuzzy OR

2.4.3 Fuzzification and membership functions

The fuzzy set is a powerful tool and allows us to represent objects or members in a vague or ambiguous way. The fuzzy set also provides a way that is similar to a human being's concepts and thought process. However, just the fuzzy set itself cannot lead to any useful and practical products until the fuzzy inference process is applied. To implement fuzzy inference to a real product or to solve an actual problem, as we discussed before, three consecutive steps are needed, which are: Fuzzification, fuzzy inference and defuzzification.

Fuzzification is the first step to apply a fuzzy inference system. Most variables existing in the real world are crisp or classical variables. One needs to convert those crisp variables (both input and output) to fuzzy variables, and then apply fuzzy inference to process those data to obtain the desired output. Finally, in most cases, those fuzzy outputs need to be converted back to crisp variables to complete the desired control objectives.

Generally, fuzzification involves two processes: derive the membership functions for input and output variables and represent them with linguistic variables. This process is equivalent to converting or mapping classical set to fuzzy set to varying degrees.

In practice, membership functions can have multiple different types, such as the triangular waveform, trapezoidal waveform, Gaussian waveform, bell-shaped waveform, sigmoidal waveform and S-curve waveform. The exact type depends on the actual applications. For those systems that need significant dynamic variation in a short period of time, a triangular or trapezoidal waveform should be utilized.

For those system that need very high control accuracy, a Gaussian or S-curve waveform should be selected [9].

2.4.4 Fuzzy control rules

Fuzzy control rule can be considered as the knowledge of an expert in any related field of application. The fuzzy rule is represented by a sequence of the form IF- THEN, leading to algorithms describing what action or output should be taken in terms of the currently observed information, which includes both input and feedback if a closed-loop control system is applied. The law to design or build a set of fuzzy rules is based on a human being's knowledge or experience, which is dependent on each different actual application.

A fuzzy IF-THEN rule associates a condition described using linguistic variables and fuzzy sets to an output or a conclusion. The IF part is mainly used to capture knowledge by using the elastic conditions, and the THEN part can be utilized to give the conclusion or output in linguistic variable form. This IF-THEN rule is widely used by the fuzzy inference system to compute the degree to which the input data matches the condition of a rule. Two types of fuzzy control rules are widely utilized for most real applications.

One is fuzzy mapping rules which provide a functional mapping between the input and the output using linguistic variables. The foundation of a fuzzy mapping rule is a fuzzy graph, which describes the relationship between the fuzzy input and the fuzzy output.

Sometimes, in real applications, it is very hard to derive a certain relationship between the input and the output, or the relationship between those inputs and outputs are very complicated even when that relationship is developed.

Fuzzy mapping rules are a good solution for those situations. Fuzzy mapping rules work in a similar way to human intuition or insight, and each fuzzy mapping rule only approximates a limited number of elements of the function, so the entire function should be approximated by a set of fuzzy mapping rules. The other type of fuzzy control rule is a fuzzy implication rule describes a generalized logic implication relationship between inputs and outputs. The foundation of a fuzzy implication rule is the narrow sense of fuzzy logic. Fuzzy implication rules are related to classical two-valued logic and multiple valued logic.

2.4.5 Defuzzification and the lookup table

The conclusion or control output derived from the combination of input, output membership functions and fuzzy rules is still a vague or fuzzy element, and this process in called fuzzy inference. To make that conclusion or fuzzy output Fundamentals of Fuzzy Logic Control available to real applications, a defuzzification process is needed. The defuzzification process is meant to convert the fuzzy output back to the crisp or classical output to the control objective. Remember, the fuzzy conclusion or output is still a linguistic variable, and this linguistic variable needs to be converted to the crisp variable via the defuzzification process. Three defuzzification techniques are commonly used, which are: Mean of Maximum method, Center of Gravity method and the Height method. The terminal product of defuzzification is the lookup table. Defuzzification needs to be performed for each subset of a membership function, both inputs and outputs.

2.5Modal Reference Fuzzy Adaptive Control

Model Reference Adaptive Control (MRAC) is one of the ways to deal with the uncertainties of plants. Industrial drives are usually subjected to uncertainties in many ways and MRAC such drives are quite capable of dealing with these problems. Model reference fuzzy adaptive controller (MRFAC) of DC drives subjected to disturbances and uncertainties avoids all these complexities. An input to the plant (which consists of the converter and dc drive) such that the scalar output error(ed) between the outputs of the plant and RM approaches zero [10].

In this thesis, a fuzzy adaptive process is developed and used instead of conventional algorithms in MRAC speed control system. Such a fuzzy adaptive process is based on a suitable set of fuzzy rules, which are carried out from the knowledge on the behavior of the control system. Fuzzy adaptive control scheme combines fuzzy logic control and adaptive control for controlling nonlinear, time-varying and structurally partially known system. A fuzzy adaptive controller can generate or modify a fuzzy controller's knowledge base in order to cope up with nonlinear and time varying characteristics of the system so that the closed loop system meets the desired specifications. In Model Reference Adaptive Control (MRAC) scheme, the adaptive gain k(t) is varied according to an adaptive law. The same can be obtained by fuzzy logic methods, which results in Model Reference Fuzzy Adaptive Control (MRFAC) scheme [11].

A schematic representation of MRFAC scheme is shown in Figure (2.19) to enhance the control performance, a reference model can be adopted to generate the desired response trajectory, and the error between the outputs of the reference model and the plant is used to drive the fuzzycontroller. The reference model is chosen according to the control specifications and the speed controller of the drive is a simple proportional type.

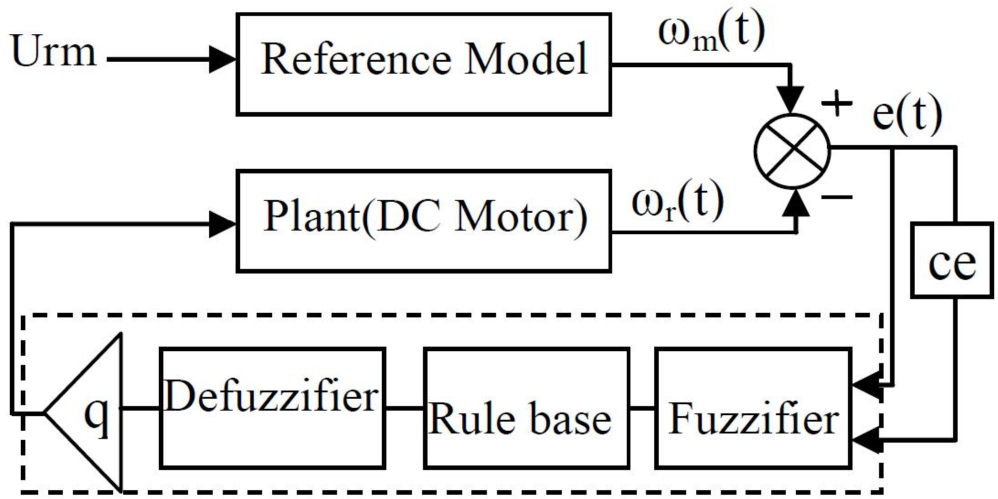

Figure 2.19: Basic control diagram for MRFAC scheme

CHAPTER THREE

Material and Methods

3.1System Modeling

A model is a precise representation of a system's dynamics used to answer questions via analysis and simulation. The general term system description, loosely speaking, refers to a mathematical expression that appropriately relates the physical system quantities to the system components. This mathematical relation constitutes the mathematical model of the system [12].

3.1.1 Mathematical model of DC motor

A sketch of the basic components of DC motor is given in the Figure (3.1). The non-turning part called stator has magnets which establish a field across the turning part (called the rotor).The stator is wound with wire and current is forced through this winding called the field winding. For a constant field current if the magnetic flux Ø is constant; the magnetic flux may be varying the field current.

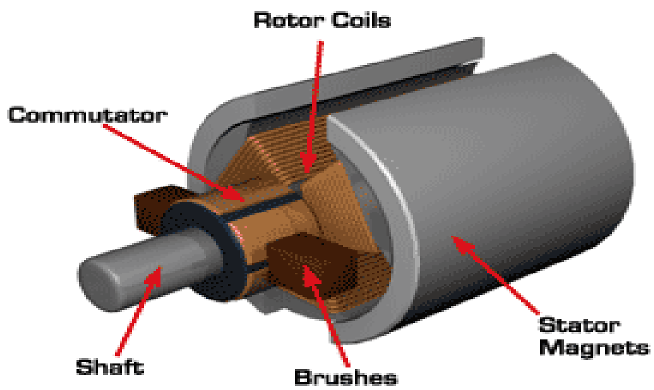

Figure 3.1: Basic Component of DC motor

The rotor is wound with wire and through this winding (called the armature winding) a current $ia$is forced through the (stationary) brushes and the (rotating) commutator. The reaction of the magnetic flux Ø with the armature current i_a produce a torque T_m that forces the armature to rotate.

$$T_m = K_{m1} Ø\, i_a \qquad (3\text{-}1)$$

Where K_{m1} constant

In servo application, a wound-field DC motor is generally used in the linear range of magnetization; the flux Ø is there for proportional to field current if and

$$T_m = K_{m2}\, if\ i_a \qquad (3.2)$$

Where K_{m2} is a constant.

The relationship among the back emf $(volt)e_b$, Rotor velocity ω (rad/sec) and flux Ø (Webers) is

$$e_b = K_{m1} \text{Ø}\, \omega \qquad (3.3)$$

$$e_b = K_{m2}\ i_f\ \omega(3.4)$$

Where K_{m1} is a constant, for the wound-field motor

Where K_{m2} is a constant. Equations (3.1 to 3.4) form the basis of DC motor operation.

In a permanent-magnet (PM) motor, the flux Ø is constant; the torque Tm exerted on the motor rotor can therefore be controlled by varying the armature current. If the direction of the armature current is reversed the direction of the torque is reversed. The torque may be controlled by varying the armature current and/or the field current.

i Armature controlled DC motor

The symbolic representation of armature-controlled DC motor as a control system component is shown in Figure (3.2).

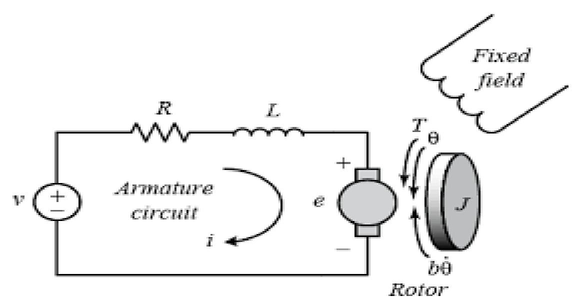

Figure 3.2: Equivalent circuit of DC motor

An external DC source supplies a constant current $i_f$to the field winding. The armature circuit consists of the armature resistance R_a and the armature inductanceL_a , e_a is the applied armature voltage which controls the motor operation and e_b is the back .On the mechanical side, the motor rotor and the attached load can be treated as inertia and viscous friction; $J\ and\ B$ are the corresponding parameters.

The variables and parameters in the DC motor model of Figure (3.2).

R_a = armature winding resistance (ohms);

L_a = armature winding inductance (henrys);

i_a = armature current (amps);

i_f = field current (amps);

V= applied armature voltage (volts);

e_b = Back emf (volts);

ω= angular velocity of the motor rotor (rad/sec);

Ө = angular displacement of the motor rotor (rad);

T_m = torque developed by the motor (newton -m);

J = moment of inertia of the motor rotor with attached mechanical load (Kg-m^2);

B= viscous friction coefficient of the rotor with attached mechanical load ((newton-m)/(rad/sec));

T_w= disturbance load torque (newton-m);

Since the field current is kept constant in the armature control equations (3.2) and (3.4) becomes

$T_m = K_T \; i_a$ (3.5)

$e_b = K_b \; \omega$(3.6)

Where K_T ≡ torque constant; K_b ≡ back emf constant

The differential equation of the armature circuit is

$$L_a \frac{di_a}{dt} + R_a i_a + e_b = V_a \quad (3.7)$$

The torque equation is

$J \frac{d\omega}{dt} + B\omega + T_w = T_m$(3.8)

Taking the Laplace transform of equations (3.5) and (3.8) assuming zero initial conditions, we get

$$T_m(s) = K_T \ (s) I_a\ (s) \quad (3.9)$$

$$E_b\ (s) = \ K_b \ \ \omega(s) \quad (3.10)$$

$$(L_a s + \ R_a) I_a\ (s) \ = \ \mathrm{V(s)} - \ E_a(s) \quad (3.11)$$

From equation 3.11 we get

$$I_a\ (s) \ \ = \frac{V(s) - \ E\ (s)}{(L_a s + R_a)} \quad (3.12)$$

$$(Js + B) w(s) \ = \ T_m(s) - T_w(s) \quad (3.13)$$

From equation (3.13) we get

$$w(s) \ = \frac{T_m(s) - T_w(s)}{(Js + B)} \quad (3.14)$$

Figure (3.3) shows a block diagram representation of the DC motor system. The block diagram gives a clear picture of the cause and effect relationships in the physical system.

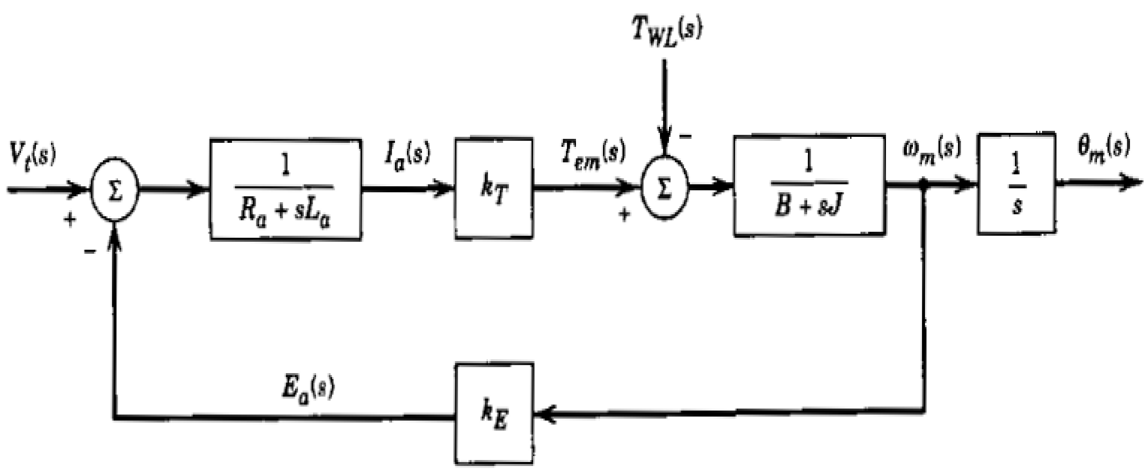

Figure 3.3: Block diagram of a DC motor

The transfer function between the motor velocity $\omega(s)$ and the input voltage E_a(s), obtained from the block diagram is

$$\frac{\omega(s)}{\mathrm{V(s)}} \quad = \quad \frac{K_T}{(L_a s + R_a)(Js + B) + K_T K_b} \quad (3.15)$$

The inductance L_a in the armature circuit is usually small and maybe neglected. If $L_a$is neglected, then the transfer function given by equation 3-15 reduced to

$$\frac{\omega(s)}{V(s)} = \frac{K_T/R_a}{Js+B+K_bK_T/R_a} \qquad (3.16)$$

The back emf constant $K_b$represents an added term to the viscous friction coefficient B. Therefore, the back emf effect is equivalent to an electric friction which tends to improve the stability of the DC motor system. The transfer function given be equation (3.16) may be written in the form given below [13].

$$\frac{\omega(s)}{V(s)} = \frac{K_m}{1+T_m(s)} (3.17)$$

Where $K_m = \frac{K_T}{R_aB+K_bK_T}$ = Motor gain constant

And

$T_m = \frac{R_aJ}{R_aB+K_bK_T}$ = Motor time constant

3.1.2 Simulink model of DC motor

SIMMULINK has become the most widely used software package in academia and industry for modeling and simulating dynamic systems. SIMULINK is a software package for modeling, simulating and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time or a hybrid of two. To simulate DC Motor MATLAB SIMULINK has used. The transfer function of DC motor directly implemented in SIMULINK also as in the Figure (3.4).

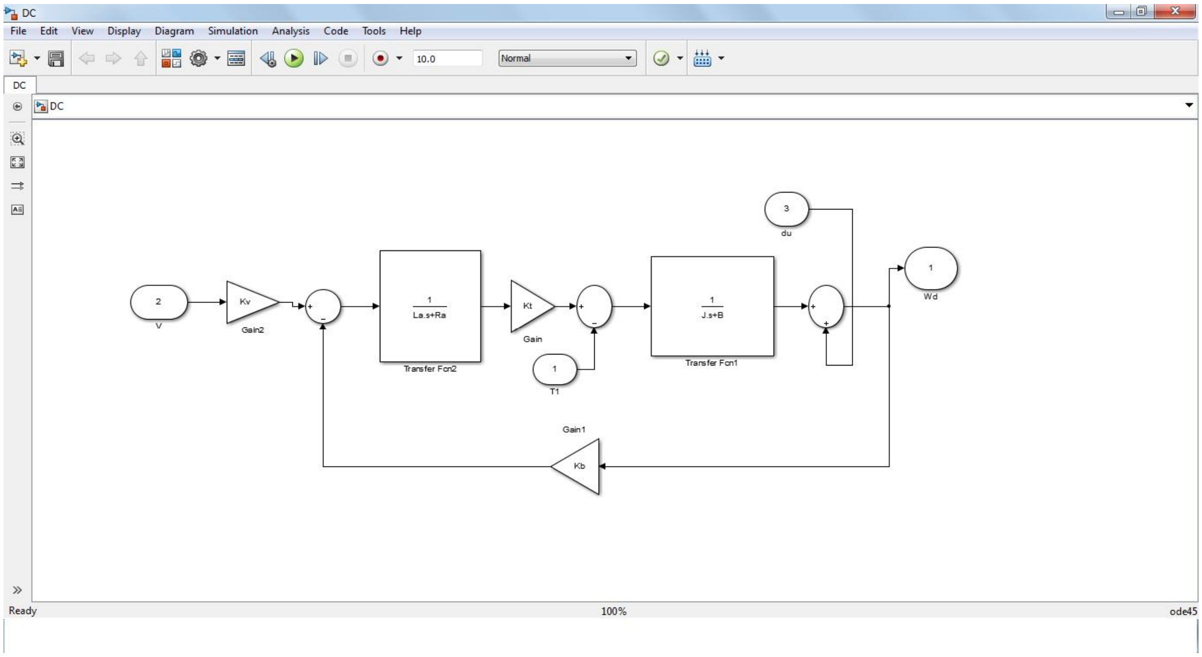

Figure 3.4: Building of DC motor by using SIMULINK

Figure (3.5) shows the open loop system of DC motor, when the input is unit step.

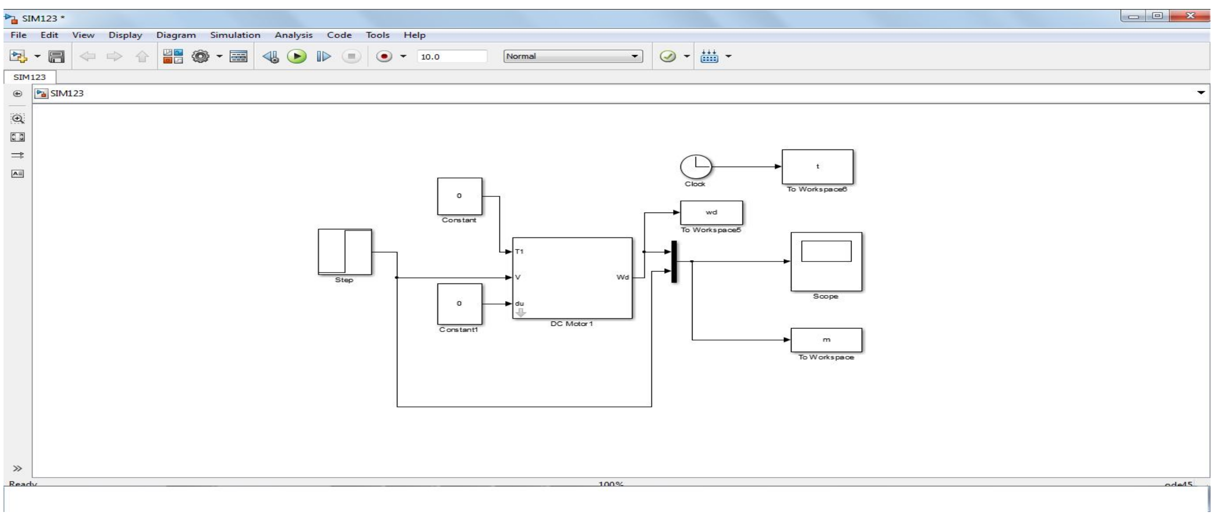

Figure 3.5: the open loop system of DC motor

The simulation result of DC motor for unit step is shown in Figure (3.6), the parameters of DC motor considered for simulation separately excited DC motor are Km = Kb = 0.55 , Ra = 1 , La = 0.046 H, J = .093 Kgm^2, B = 0.08Nmm/s/rad [14].

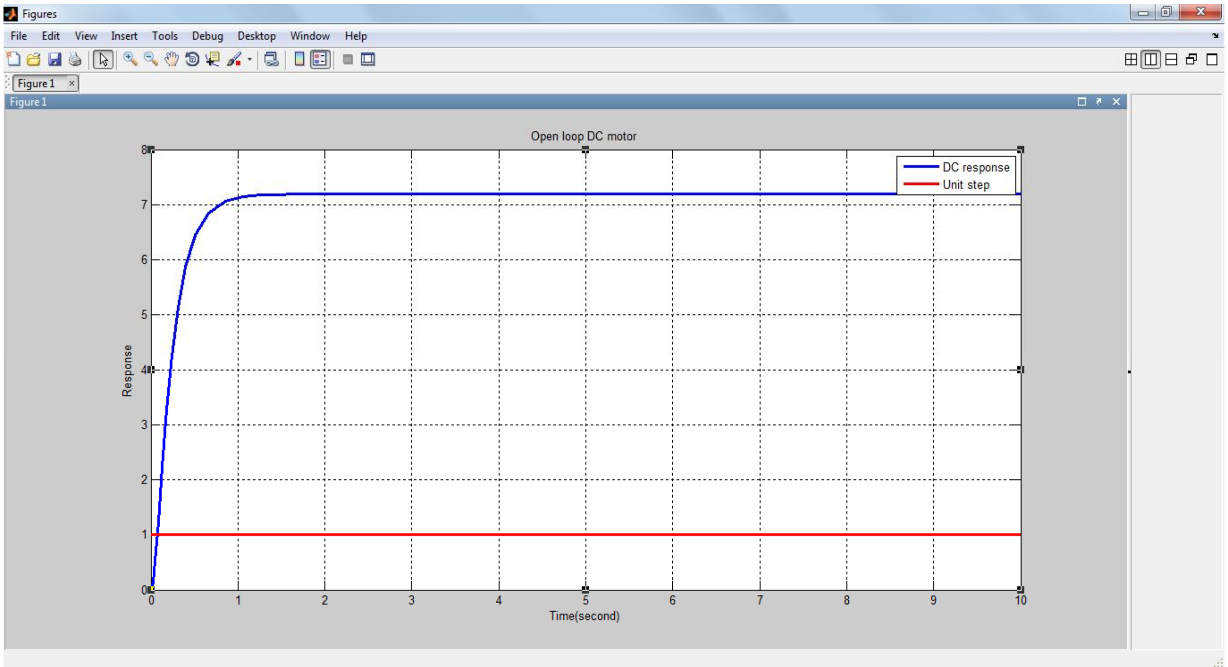

Figure 3.6: the simulation result of DC motor

3.2PID Controller Design for DC Motor

These days, PID controllers are widely used in industry because of their simplicity in structure and their applicability to a variety of processes. The input to PID is error signal which can be described by the difference between reference signal and the output signal. The output of PID controllers is the sum of three terms: proportional term, integral term and the derivative term. The transfer function of PID is represented as:

$$U(t) = K_P \left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d \frac{d(t)}{dt}\right] (3.18)$$

Where Kp is the Proportional gain, Ki is the Integral gain, Kd is the Derivative gain, e (t) is the error signal. MATLAB SIMULINK program has been used to design a PID controller as shown in the figure (3.7). The PID controller will control step input terminal in the back converter. At several set points, output from the PID controller will generate different values. Building onthat, average voltage supply to the voltage terminal of the DC motor and speed of the DC motor can be varied.

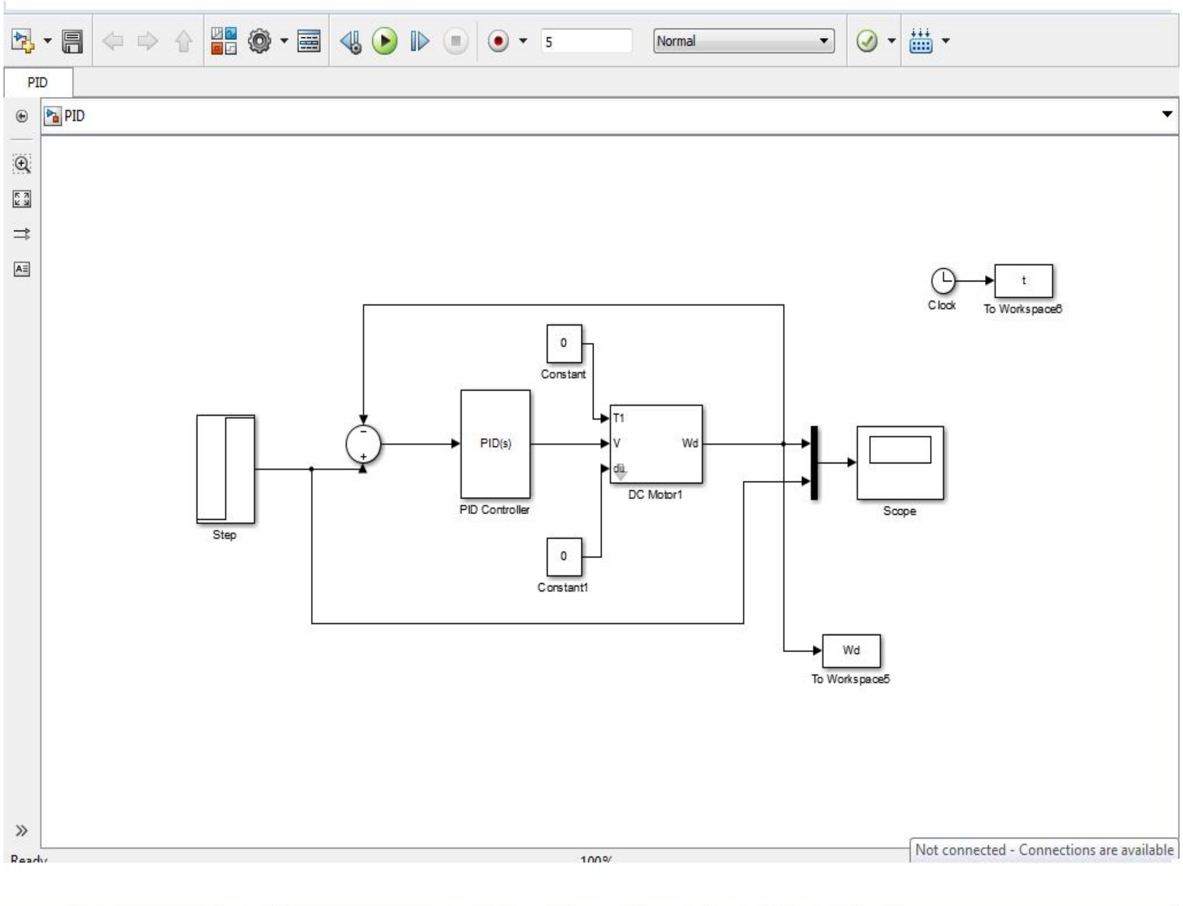

Figure 3.7: PID Controller design by using SIMULINK

To obtain the optimum gain value for KP, Ki and Kd, several gain value have been tested. The best combinations of gain value are chosen with respect to minimum overshoot, minimum steady state error and minimum steady state time. The simulation result of a PID controller of DC motor is shown in Figure (3.8).

The simulation results of using speed PID controllers with the DC motor and explains the effect of using the PID for controlling the DC motor. The parameters that have been used are Kp = 0.231, Ki = 6.155 and Kd 0.0002.

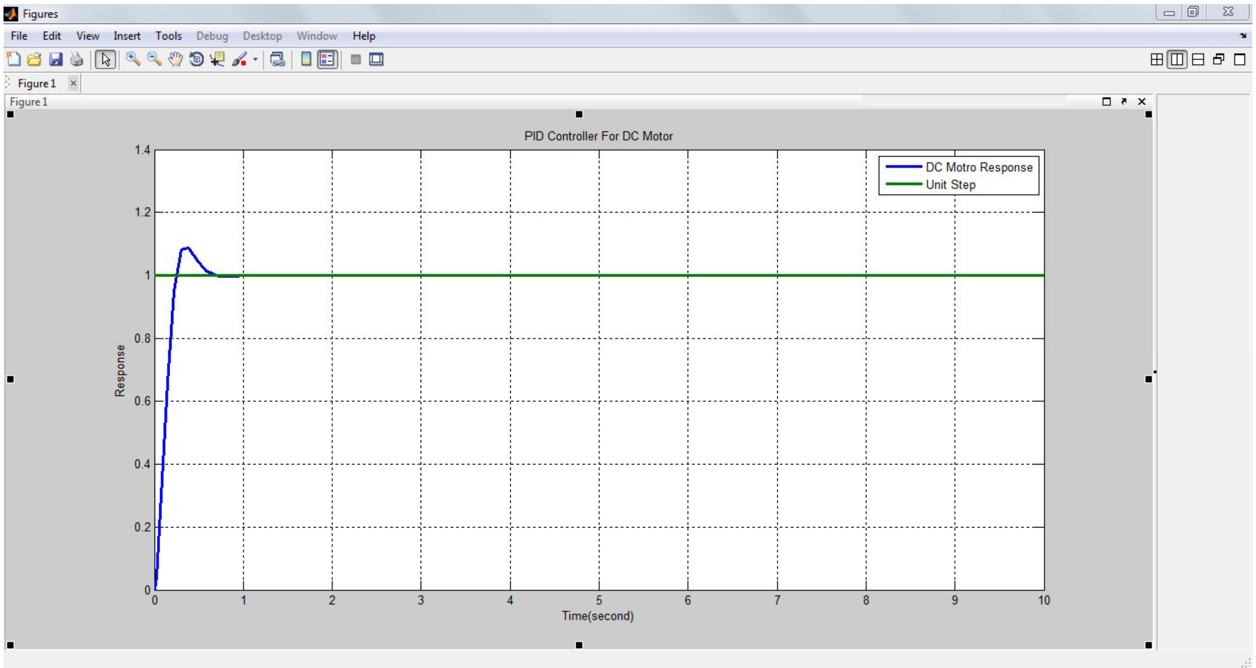

Figure 3.8:the simulation of PID controller of DC motor

3.3 MRAC Design for DC Motor

When the plant parameters and the disturbance are varying slowly or slower than the dynamic behavior of the plant, then a MRAC control can be used. The model reference adaptive control scheme is shown in Figure (3-9). The adjustment mechanism uses the adjustable parameter known as control parameter to adjust the controller parameters. The tracking error and the adaptation law for the controller parameters were determined by MIT rule [7].

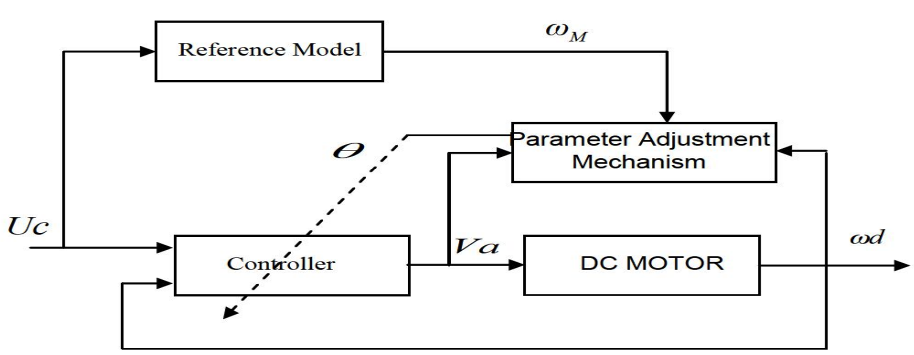

Figure 3.9: Structure of model reference adaptive control

MIT (Massachusetts Institute of Technology) Rule is that the time rate of change of $\theta$is proportional to negative gradient of the cost function (J) that is :

$$\frac{d\theta}{dt} = -\gamma \frac{\partial J}{\partial \theta} = -\gamma \varepsilon \frac{\partial \varepsilon}{\partial \theta} \quad (3.19)$$

The adaptation error.$\varepsilon = Y_p(t) - Y_m(t)$. The components of $\frac{d\varepsilon}{d\theta}$ are the sensitivity derivatives of the error with respect to the adjustable parameter vector Θ. The parameter γ is known as the adaptation gain. The MIT rule is a gradient scheme that aims to minimize the squared model error from cost function ε^2 from cost function

$$J(\Theta) = \frac{1}{2}\varepsilon^2(t) \quad (3.20)$$

*Modeling of DC motor:*The plant used in simulation is separately excited DC motor with dynamic equations as

$$W_d = W + d_L + d_u \quad (3.20)$$

$$L_a \frac{di_a}{dt} + R_a i_a + K_b \omega = V_a \quad (3.22)$$

$$K_m + I_a = Bw + J\frac{d}{dt}w + T_L \quad (3.23)$$

Taking Laplace transform of equations (3.22) and (3.23), the transfer function of the DC motor with no load torque and uncertainties (d =0) is obtained from let T_L = 0.

$$\frac{W(s)}{V(s)} = \frac{\frac{K_m}{JL_a}}{[S^2+\left(\frac{JR_a+BL_a}{JL_a}\right)S+\frac{BR_a+K_mK_d}{JL_a}]} \quad (3.24)$$

First let us consider the case with only load disturbances TL≠ 0

$$d_L = \frac{-T_L\left(\frac{R_a}{JL_a}+s\left(\frac{1}{J}\right)\right)}{\left[S^2+\left(\frac{JR_a+BL_a}{JL_a}\right)s+\frac{BR_a+K_mK_d}{JL_a}\right]} \quad (3.25)$$

Model Reference Adaptive PID Control, The goal is to develop parameter adaptation laws for a PID control algorithm using MIT rule [15].

The reference model for the MRAC generates the desired trajectory$Y_m(t)$. , which the DC motor speed $Y_p(t)$ has to follow. Standard second order differential equation was chosen as the reference model given by:

$$H_M(s) = \frac{b_M}{S^2+aM_1S+aM_0} \quad (3.26)$$

Consider also the adaptive law of MRAC structure taken as the following form:

$$U(t) = (K_P e(t) + K_i \int e(t)dt - K_d e^*(t) Y_p) \quad (3.27)$$

Where; e (t) =$U_c - Y_p$, K_P is proportional gain, Ki is integral gain, Kd is derivative gain and uc is a unit step input. In the Laplace domain, equation (3-27) can be transformed to:

$$U = (K_P E + \frac{K_i}{S} E - SK_d Y_p) \quad (3.28)$$

It is possible to show that applying this control law to the system gives the following closed loop transfer function:

$$Y_p = G_P\left(\left(K_P + \frac{K_i}{S}\right)\left(U_c - Y_p\right) - SK_d Y_p\right) \quad (3.29)$$

Apply MIT gradient rules for determining the value of PID controller parameters ($K_p{}^*$, $K_i{}^*$and $K_d{}^*$). The tracking error equation (3.26) satisfies:

$$\varepsilon = \frac{(G_P K_P S + G_P K_i)U_c}{[(1+G_P K_P) + G_P K_i + S^2 G_P K_d]} - Y_m \quad (3.30)$$

The exact formulas that are derived using the MIT rule cannot be used. Instead some approximations are required. An approximation made which valid when parameters are closed to ideal value is as follows

Denominator of plant ≅ Denominator model reference then, from gradient method [14].

$$\frac{dK}{dt} = -\gamma \frac{\partial J}{\partial K_i} = -\gamma\left(\frac{\partial J}{\partial \varepsilon}\right)\left(\frac{\partial \varepsilon}{\partial Y}\right)\left(\frac{\partial y}{\partial K}\right) \quad (3.31)$$

Where; $\left(\frac{\partial J}{\partial \varepsilon}\right) = \varepsilon$, $\left(\frac{\partial \varepsilon}{\partial Y}\right) = 1$

Then the approximate parameter adaptation laws are as follows

$$K_p{}^* = \left(\frac{-\gamma_P}{S}\right) \varepsilon \left(\frac{S}{a_0 S^2 + a_{m1} S + am_2}\right) \quad (3.32)$$

$$K_i{}^* = \left(\frac{-\gamma_i}{S}\right) \varepsilon \left(\frac{1}{a_0 S^2 + a_{m1} S + am_2}\right) e \quad (3.33)$$

$$K_d{}^* = \left(\frac{\gamma_d}{S}\right) \varepsilon \left(\frac{S^2}{a_0 S^2 + a_{m1} S + am_2}\right) e \quad (3.34)$$

Some simulation carried out for MRAC Separately Excited DC motor controller. MATLAB software was used for the simulation of control systems. Figure (3.10) shows SIMULINK models for both MRAC along with the motor under control. The parameters of separately excited DC motor are considered as: Km = Kb = 0.55, Ra = 1, La = 0.046 H, J = 0.093 Kgm^2 , B = 0.08Nmm/s/rad.

As wellas, the second order transfer function of the Model Reference as follows:

$$H_M(s) = \frac{16}{S^2 + 4S + 16} \quad (3.35)$$

This reference model has 16% maximum overshoot, settling time of more than two seconds and rise time of about 0.45 seconds. In simulation, the constants gammas were grouped in sets as in table (3.1).

Table 3.1: Group of Gammas

γ_P	0.8
γ_i	4.0
γ_i	2.4

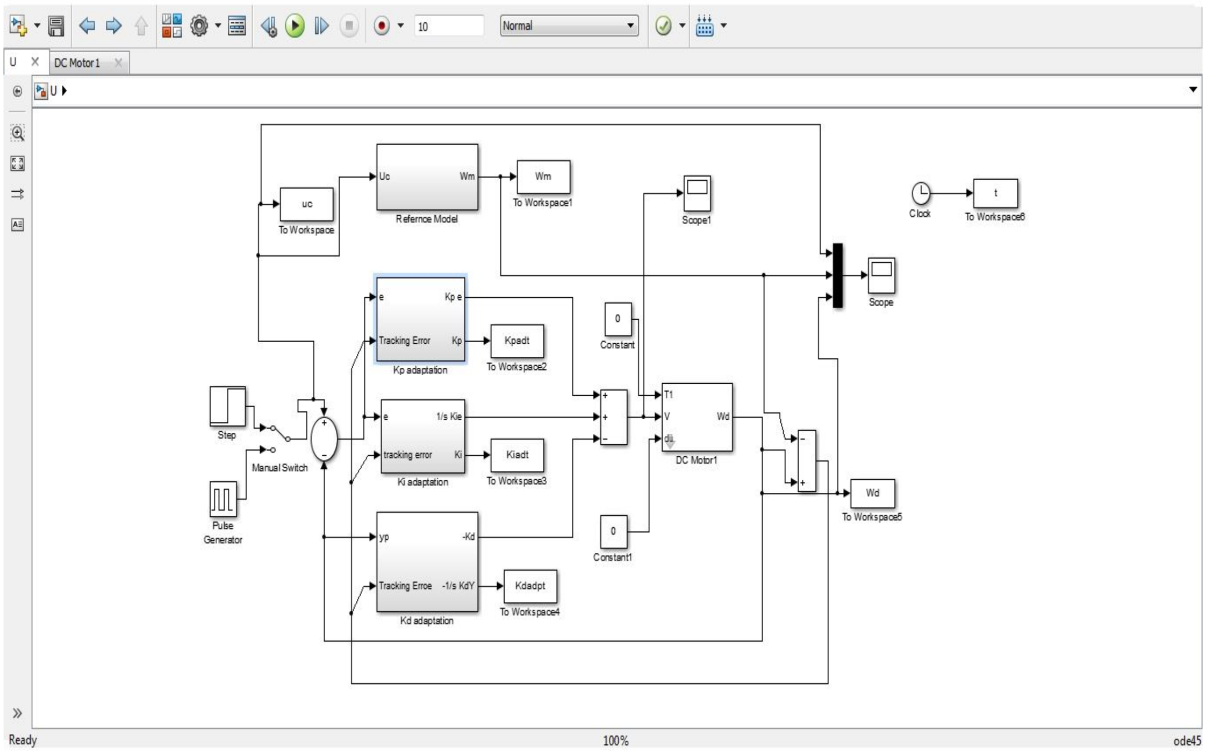

Figure *3.10: SIMULINK Model for MRAC*

Figure (3.11) shows implementation of MIT rule to obtain adaptation gains.

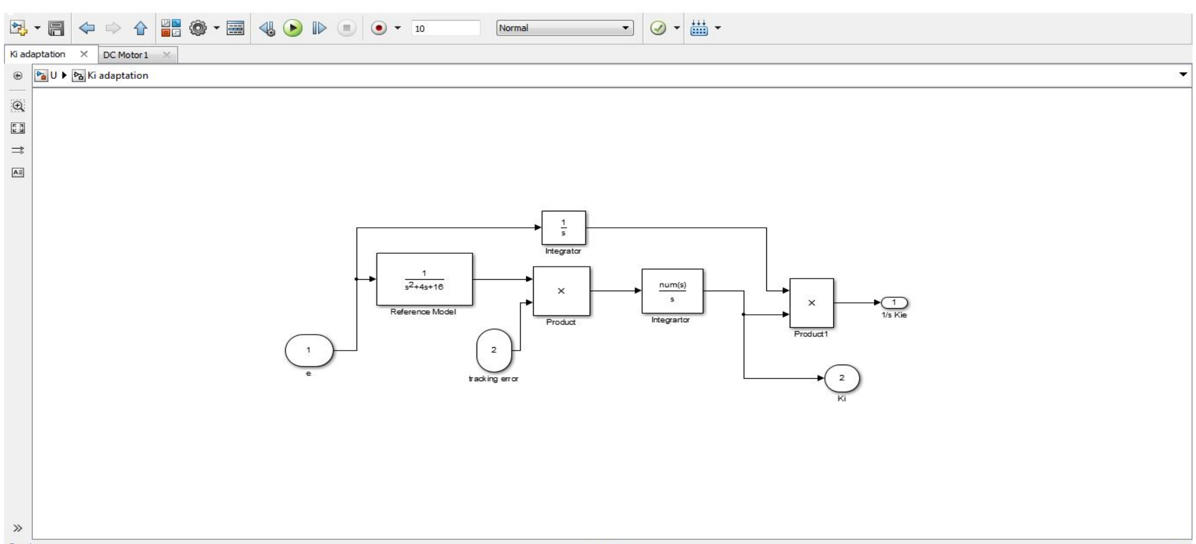

Figure *3.11: SIULINK Model for Integration Adaptation Gain (MIT rule)*

While Figure (3.12) shows the simulation result of DC motor response with MRAC and unit step.

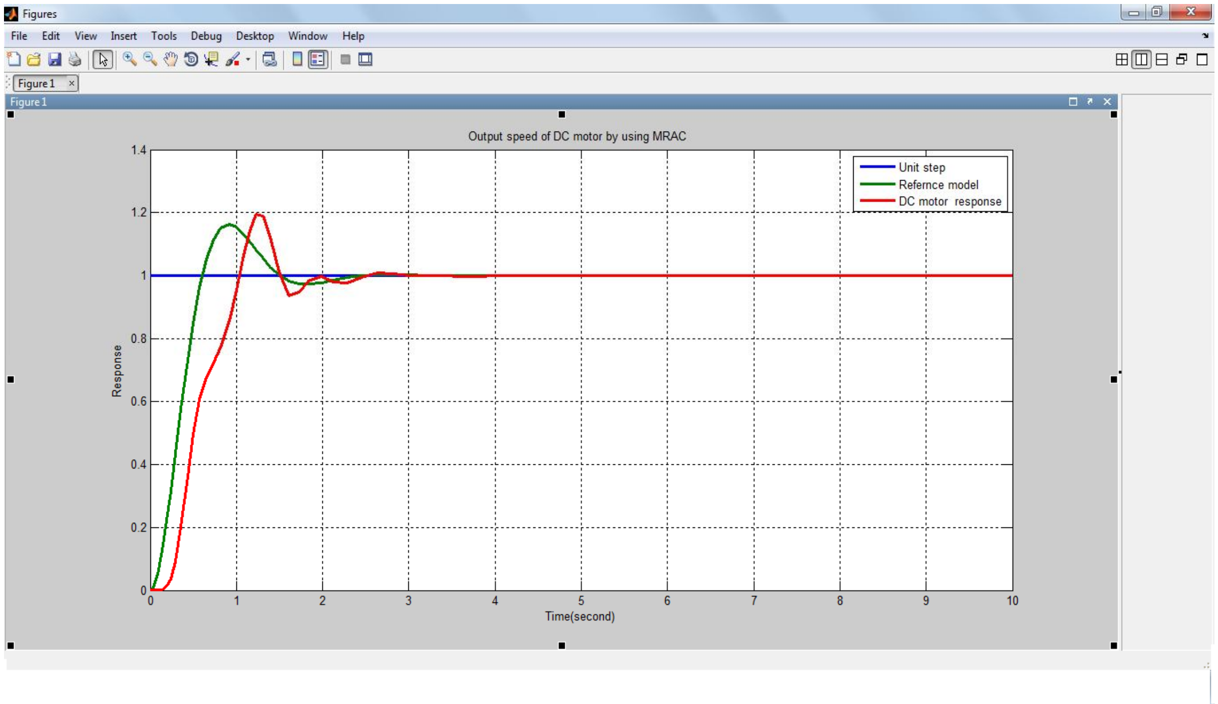

Figure 3.12: Speed response of DC motor by using MRAC

3.4 Fuzzy Controller Design for DC Motor

The speed control system under consideration is shown in Figure (3.13). The speed control loop has an inner current loop to provide fast transient response as well as to limit the armature current. The speed controller is designed in such a way to produce a desired reference signal for the current controller. The output of the current controller is fed to a gain which controls the terminal voltage. Figure (3.14) shows fuzzy implementation that are designed in this thesis with two inputs and one output. The DC motor designed and connected with the outputs from the fuzzy logic controller.

Figure (3.14) shows that the Fuzzy inference system got the parameters from the SIMULINK model for control of the DC motor using Fuzzy PD controller. FLC controller design and the performance of the controller has been analyzed and evaluated in term of percentage of maximum overshoot (OS %), rising time and settling time. In this thesis Fuzzy Logic Controller (7× 7) matrix was used. And the design of the FLC has been tested.

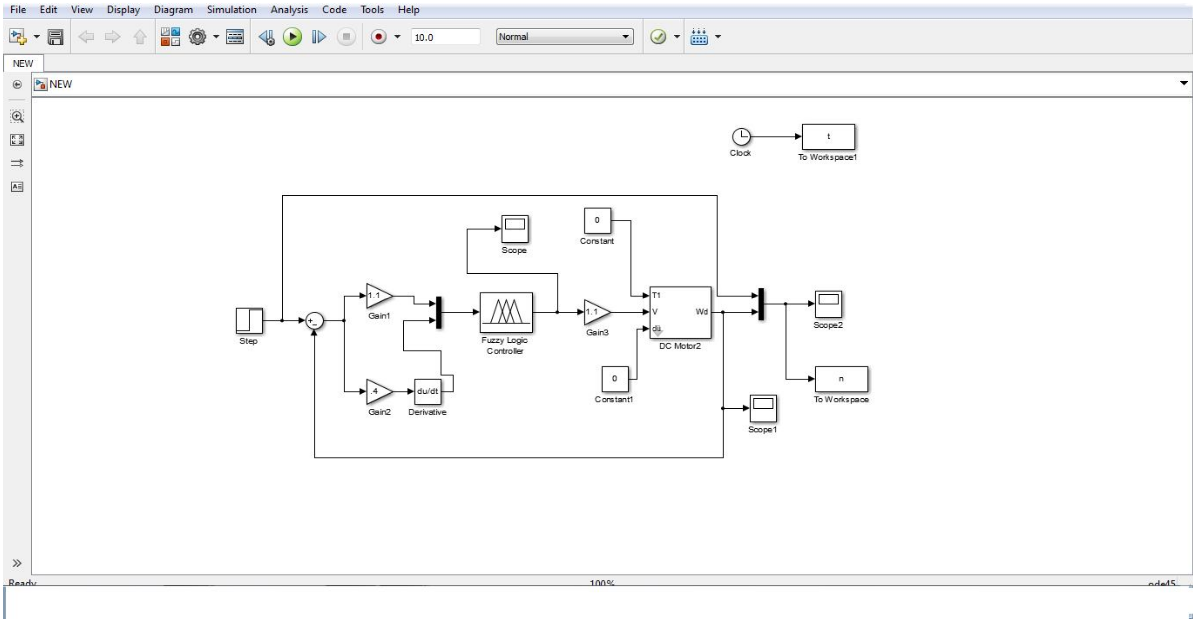

Figure 3.13: SIMULINK model for control of DC motor using the PD fuzzy controller

FLC toolbox in SIMULINK has been used. Below are general setting parameter and method that had been used for the FLC controller Fuzzy inputs are composed of seven membership functions of error and seven membership functions of error derivative. Fuzzy outputs have been control output (7×7) membership). Fuzzy Inference system was Mamdani.

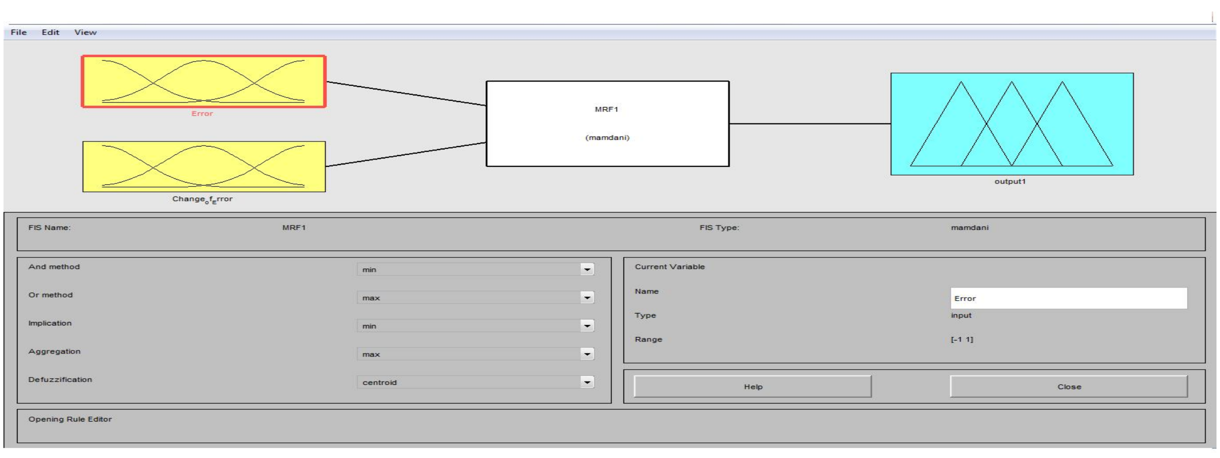

Figure 3.14: FLC controllers FIS editor

The membership functions for the error are shown in Figures (3.15) and the membership functions for error derivative are shown in Figure (3.16). These functions are assumed to be same for both the input variables.

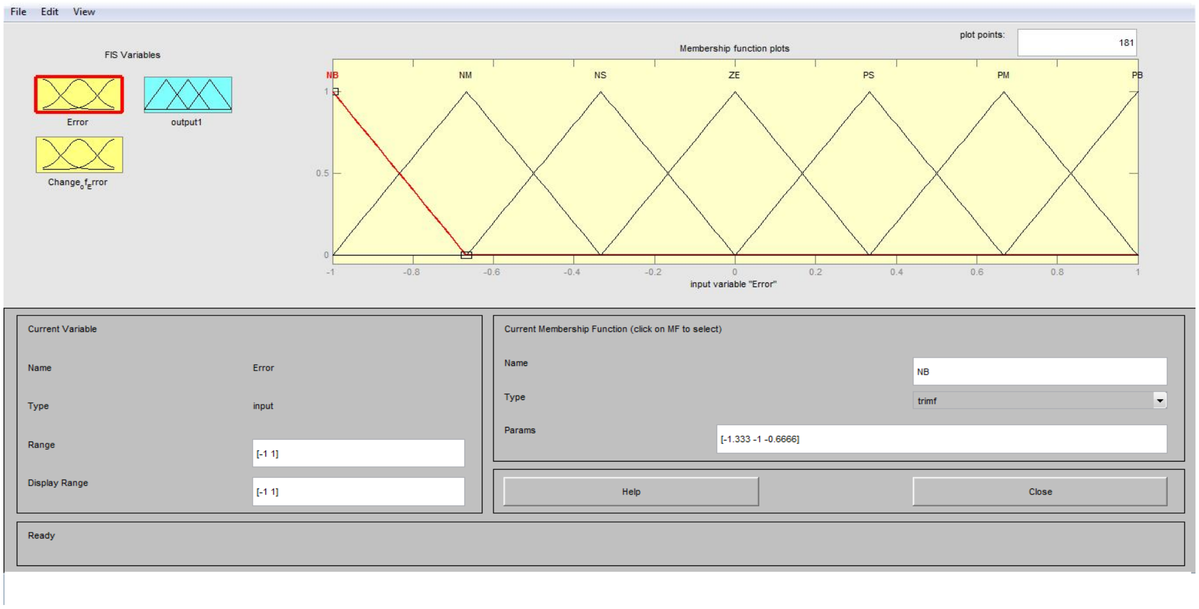

Figure 3.15: Membership functions of error

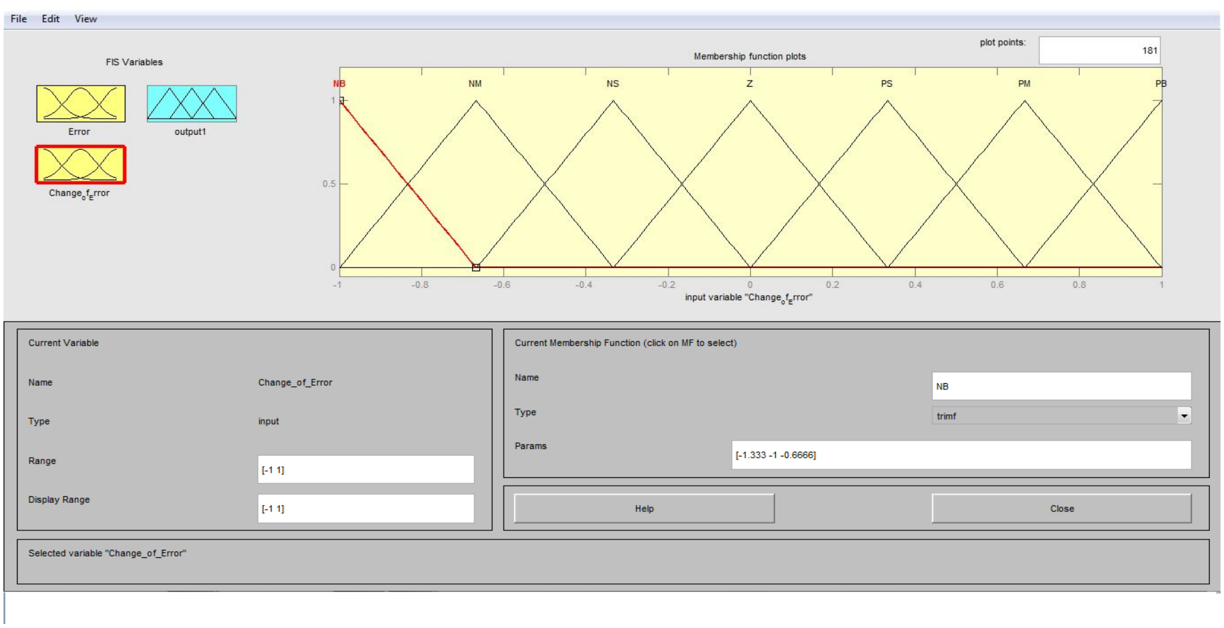

Figure 3.16: Membership functions error derivative for the fuzzy logic

Fuzzy controller has two input variables error and rate of change in error. And one output variables .The membership functions for Fuzzy output variables can be shown in Figure (3-17).

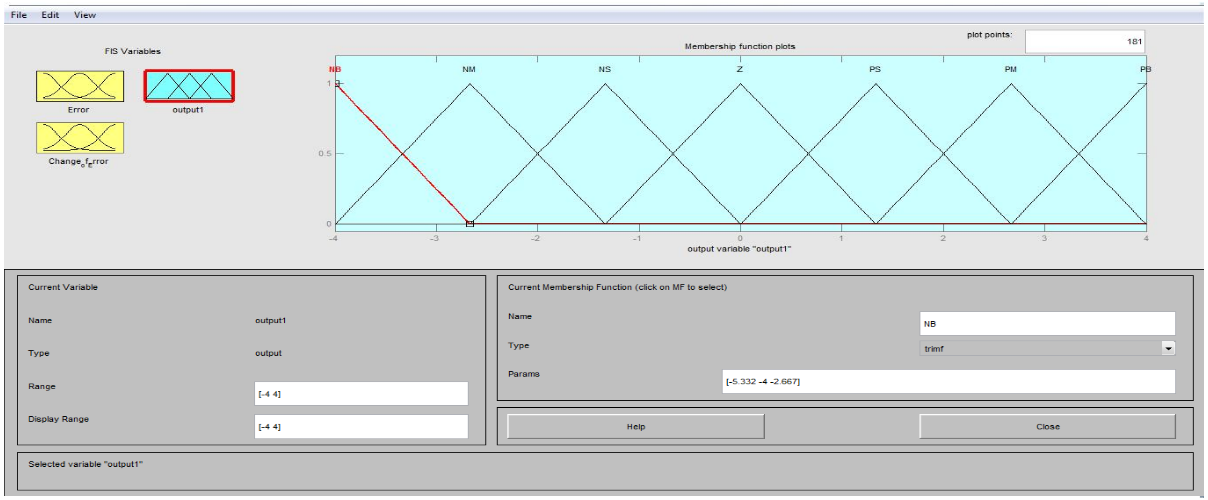

Figure 3.17: Membership functions for output

Figure (3.18) shown the simulation results for using speed fuzzy controllers with the DC motor, and explains the effect of using the fuzzy controller for controlling the speeding DC motor.

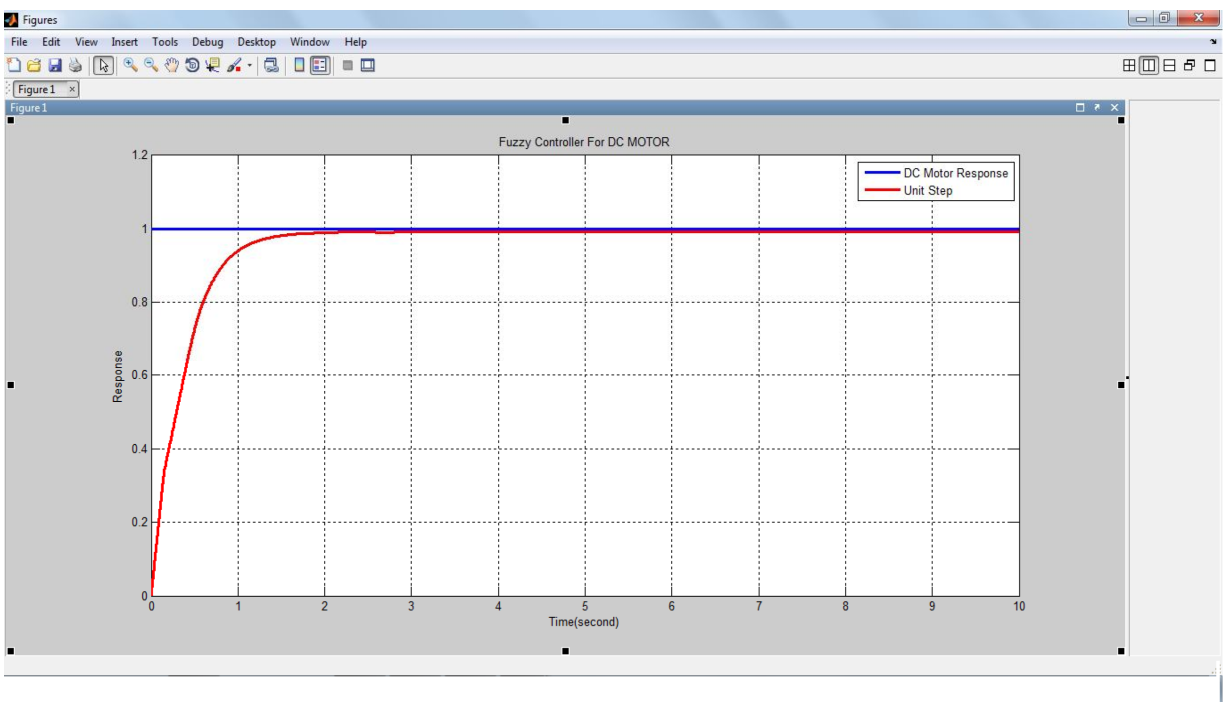

Figure 3.18: Simulation Result of using fuzzy controller

3.5 MRFAC Design for DC Motor

In Model Reference Adaptive Control (MRAC) scheme, the adaptive gain k (t) is varied according to an adaptive law. The same can be obtained by fuzzy logic methods, which results in Model Reference Fuzzy Adaptive Control (MRFAC) scheme. A schematic representation of MRFAC scheme is shown in Figure (3.19).

To enhance the control performance, a reference model can be adopted to generate the desired response trajectory, and the error between the outputs of the reference model and the plant is used to drive the fuzzy controller. The reference model is chosen according to the control specifications and the speed controller of the drive is a simple proportional type.

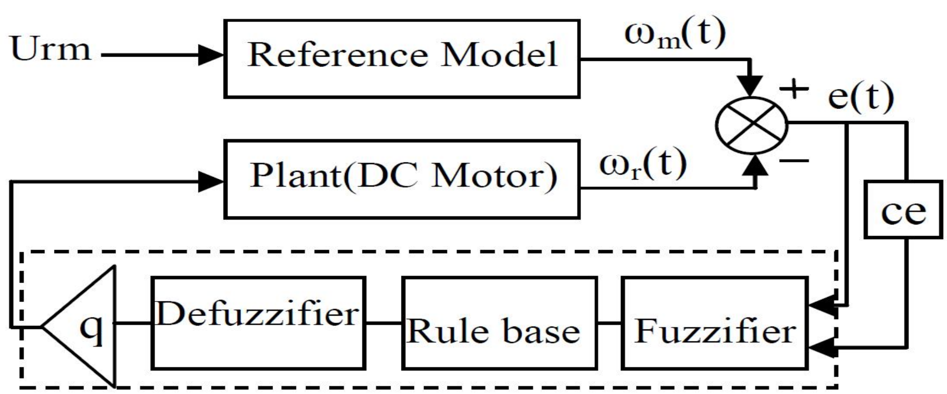

Figure 3.19: Basic control diagram for model reference fuzzy adaptive control scheme

3.5.1 Design of fuzzy adaptive controller

To design the fuzzy adaptive controller, the model following the dynamic is analyzed first, as follows. The dynamic signal analysis of the speed tracking response is implemented to acquire some information concerning the plant before designing a fuzzy controller. A step command is issued at the beginning of the time axis, as shown in Figure (3.20) and the desired motor speed step tracking response of the fuzzy adaptive controller and the output of the reference model are also sketched in Figure (3-20) The error (e) and error change (Ce) are defined as

$$e\,(t) = W_m(t) - W_d(t) \quad (3.36)$$

$$Ce\,(t) = e\,(t) - e\,(t-1) \quad (3.37)$$

Where $W_m(t)$ the response of the reference model

$W_d(t)$ the rotor position signal

e (t) the error signal

C e (t) the error change signal

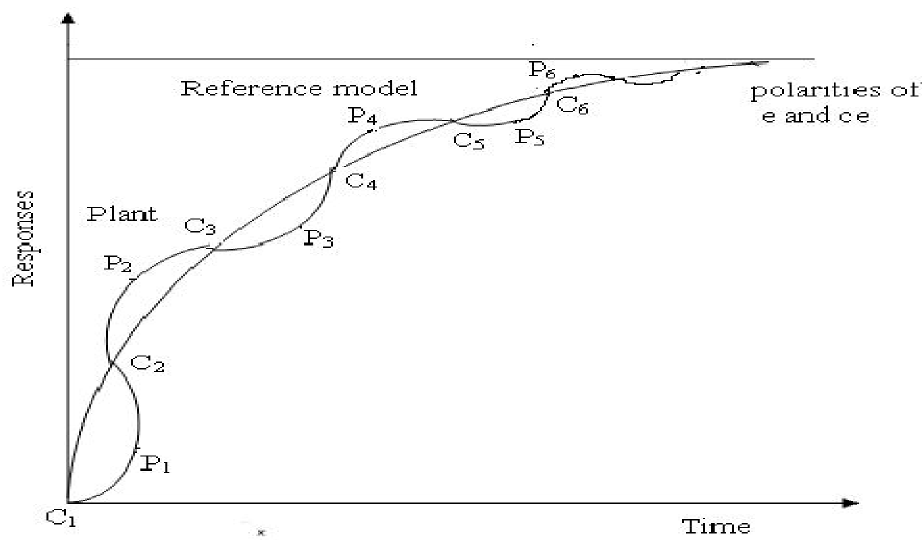

Figure 3.20: Model following characteristics in model reference fuzzy adaptive control

3.5.2 Construction of fuzzy rules

The fuzzy IF-THEN rules from human operators provide good control strategies, and then the adaptation will converge quickly. The Fuzzy logic controller has two input variables error and rate of change in error. And one output variable. 49 rules are defined using the linguistic variables, shown in table (3.2).

3.5.3 Membership Functions

The input to the fuzzy controllers is selected as error (e) between the DC drive and the

Reference model speed, and change of error (Ce) .The membership functions used for input variables is shown in Figure (3.21) and Figure (3.22).

Table 3.2: Linguistic Rule Table

e / ce CI	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZE	ZE
NM	NB	NM	NM	NS	NS	ZE	ZE
NS	NM	NM	NS	NS	ZE	ZE	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	ZE	ZE	PS	PS	PM	PM
PM	ZE	ZE	PS	PS	PM	PM	PB
PB	ZE	ZE	PS	PM	PM	PB	PB

Triangular membership functions are chosen due to of its simplicity. Figure (3.25) shows output membership functions.

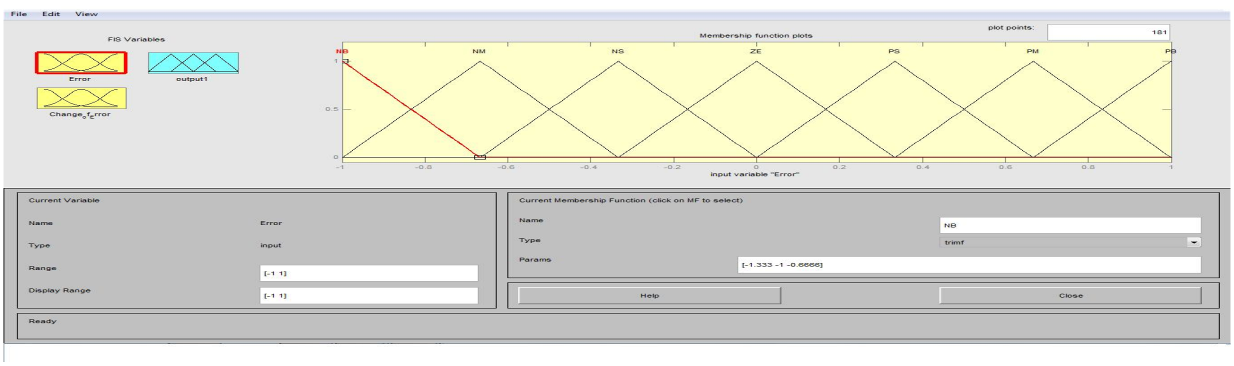

Figure 3.21: Input membership function error (e)

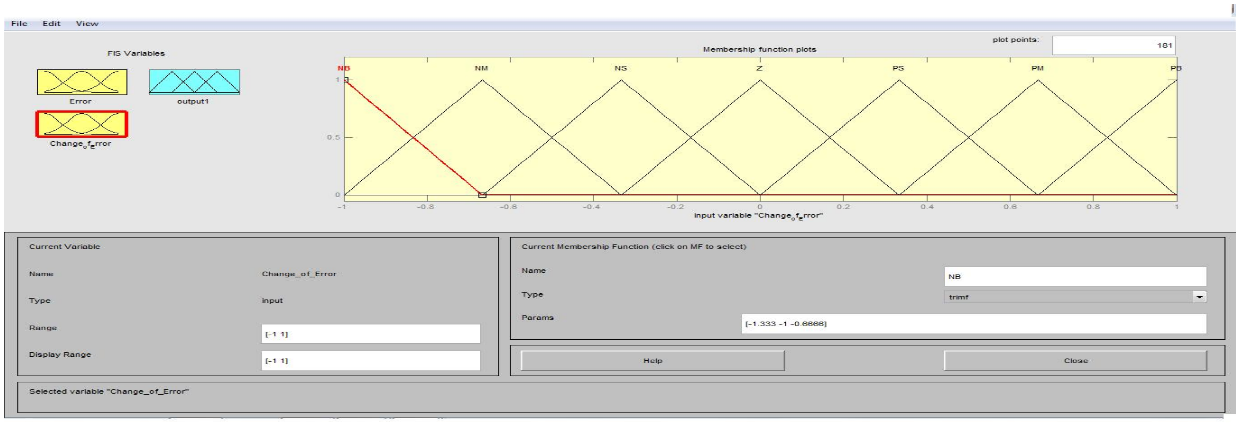

Figure 3.22: Input membership function change of error (Ce)

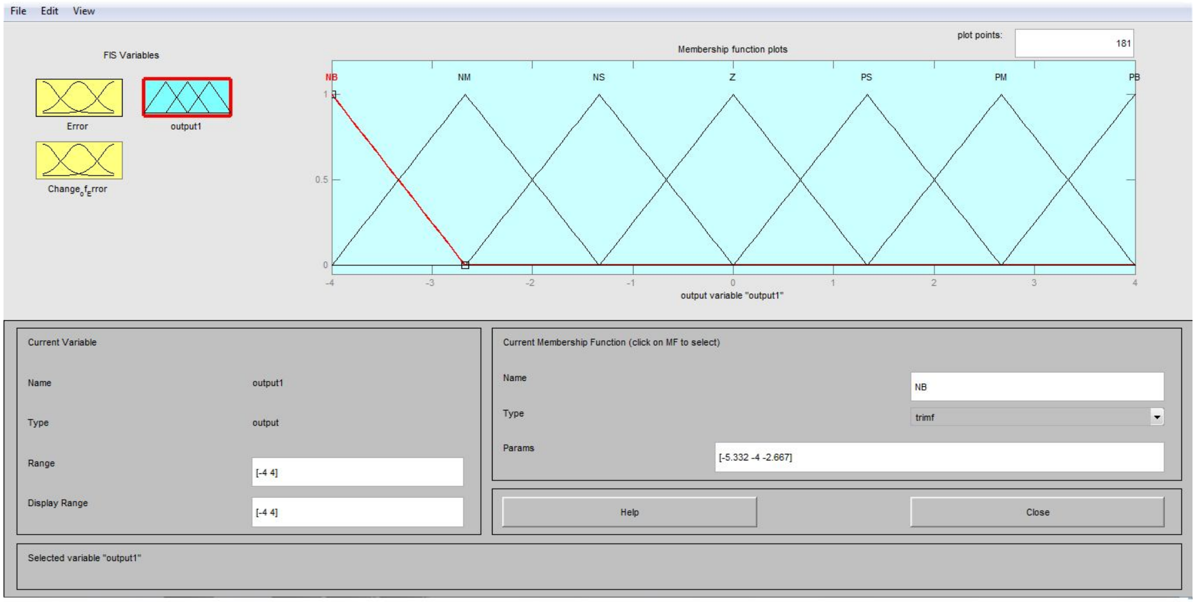

Figure 3.23:Output membership function

Fuzzy Inference system was MAMDANI and the number of rules base is 49. Figure (3.24) shows the Rule viewer got the parameters from the SIMULINK Model for Control of the DC motor.

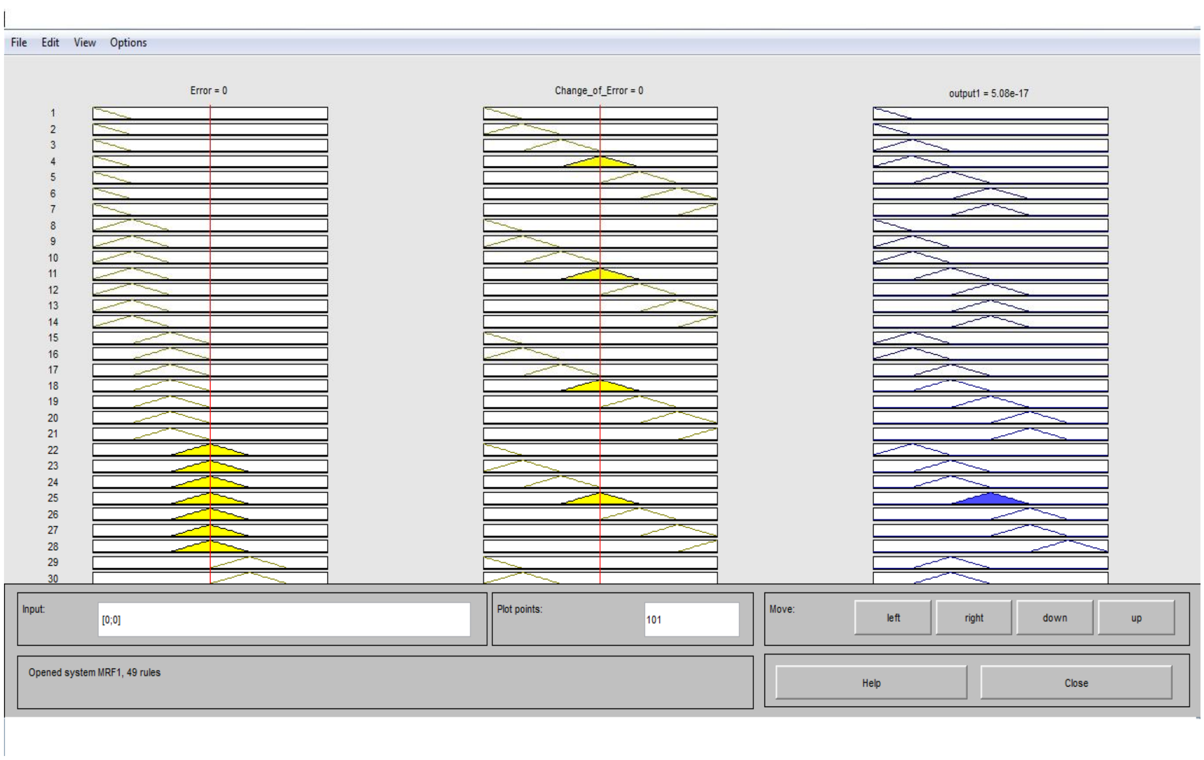

Figure 3.24:Rule viewer

Surface view shows the relation between output and e (error value) and Ce (changes of error). As shown in the Figure (3.25).

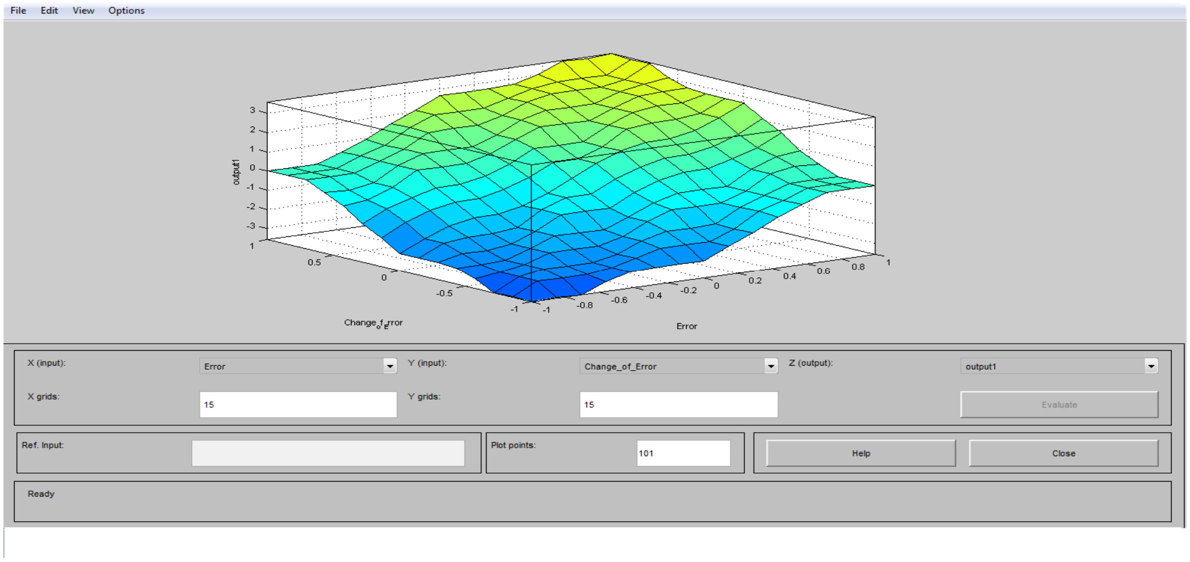

Figure 3.25: Output graphical shape

The simulations have been performed with the help of SIMULINK software. Figure (3.26) shows SIMULINK model for control of the DC motor. Simulation result is shown in Figure

(3.27).

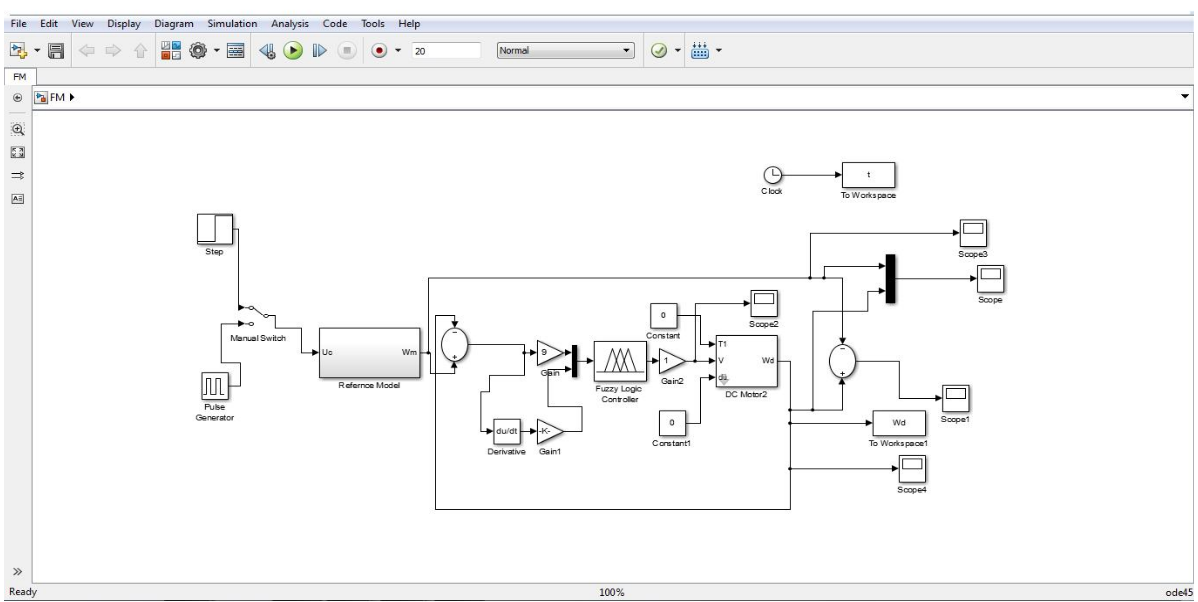

Figure 3.26:SIMULINK model for MRFAC of DC motor

With help of MATLAB SIMULINK the output time response of DC motor by using MRFAC is shown in Figure (3.27).

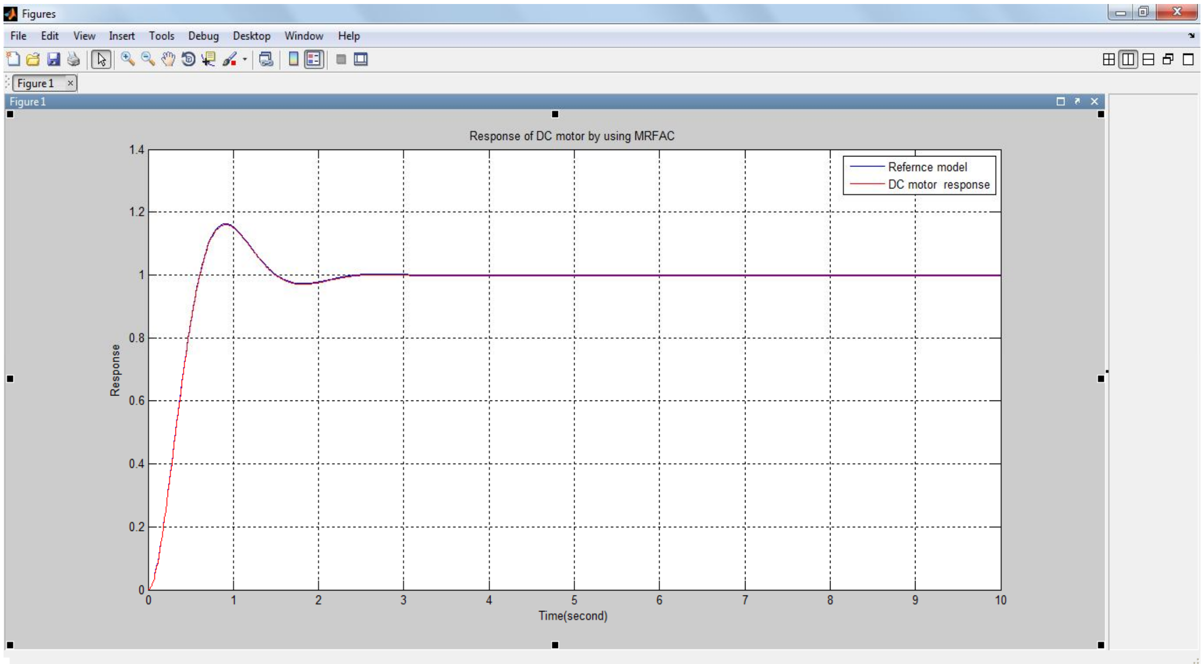

Figure 3.27: Time response of DC motor using MRFAC scheme

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The aim of simulations is to show the effectiveness of MRFAC by its performance comparison with PID controller, fuzzy controller and MRAC for DC motor unknown parameters. All results are obtained from simulation performed using MATLAB SIMULINK program .This chapter consists of five parts: The first part presents the simulation results of DC motor without controller which is obtained from figure (3.6). The second part presents the simulation result obtained using the PID controller with DC motor, which is structured from figure (3.8). The third part presents the simulation result obtained from using the controlled DC motor with MIT rule method. The fourth part presents the simulation result obtained from using PD fuzzy controller for DC motor, which is structured from figure (3.18). The fifth part presents simulation result of DC motor with MRFAC which is structured from figure (3.27). The sixth section analyzes and compares the MRFAC technique over PID, PD fuzzy and MRAC for DC motor the simulation results show the two cases of the DC motor with and without load.

In order to insure that the methods provide results which can be compared, the following criteria are used for the all control methods, the reference proposed for the simulation is unit step with time duration for simulation being 10 seconds.

The parameters of separately excited DC motor are : Km = Kb =.55, Ra = 1, La = 0.046 H, J = 0.093 Kgm^2 , B = .08Nmm/s/rad.

The reference model is designed to have, rise time t_r = 0.455 s, settling time t_s= 2.1 s and the maimum overshoot 16%.

The reference model can be obtained as

$$H_M(s) = \frac{16}{S^2+4S+16} \quad (4.1)$$

The load torque and disturbance are assumed as constant value of 0.1 and 0.1 respectively.

4.2 Simulation Result of DC Motor without Controller

For the performance of the DC motor plant without controller which has been described in the previous chapter, the simulation are shown in Figure (4.1) and Figure (4.2) that represents the speed response of DC motor without (disturbance , load) and with disturbances.

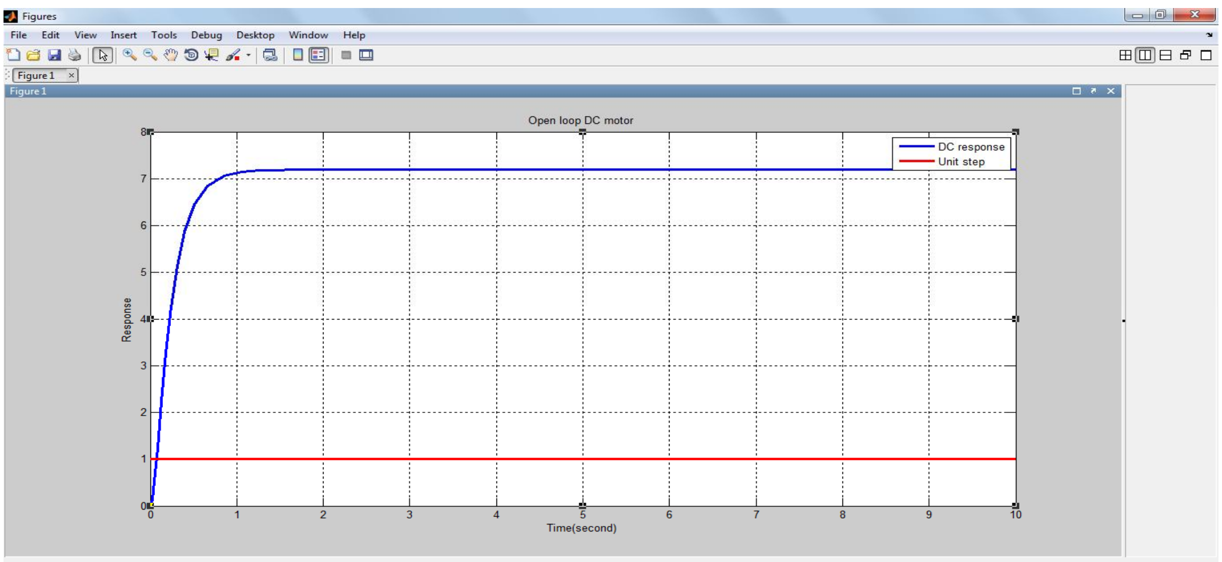

Figure 4.1: Uncontrolled DC motor time response without disturbance and load

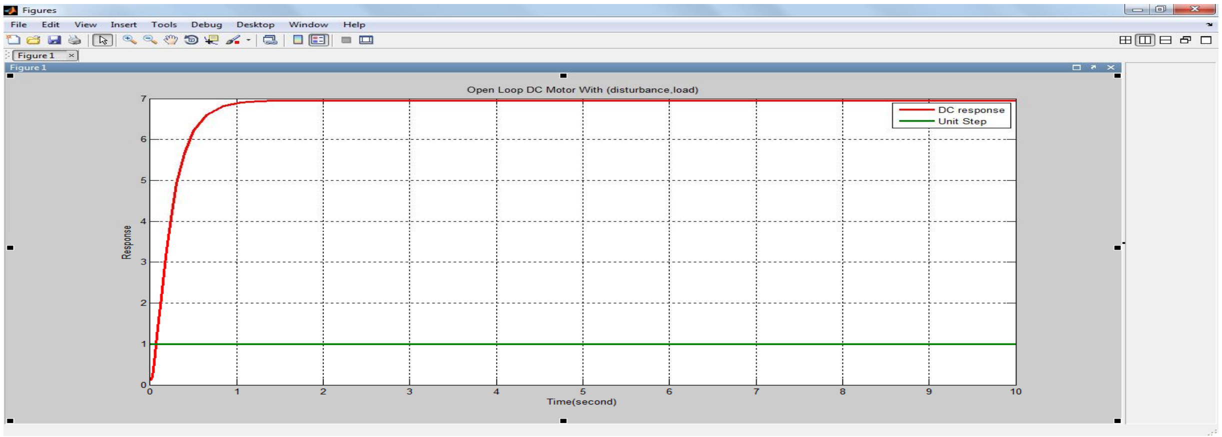

Figure 4.2: Uncontrolled DC motor time response with disturbance and load

4.3 Simulation Result of DC Motor with PID Controller

The performance of a PID controller for DC motor is shown in the Figure (4.2) and Figure (4.3) , which represents the response of DC motor without (disturbance ,load) and with (disturbance ,load) while Table (4.1)represents the parameters of PID.

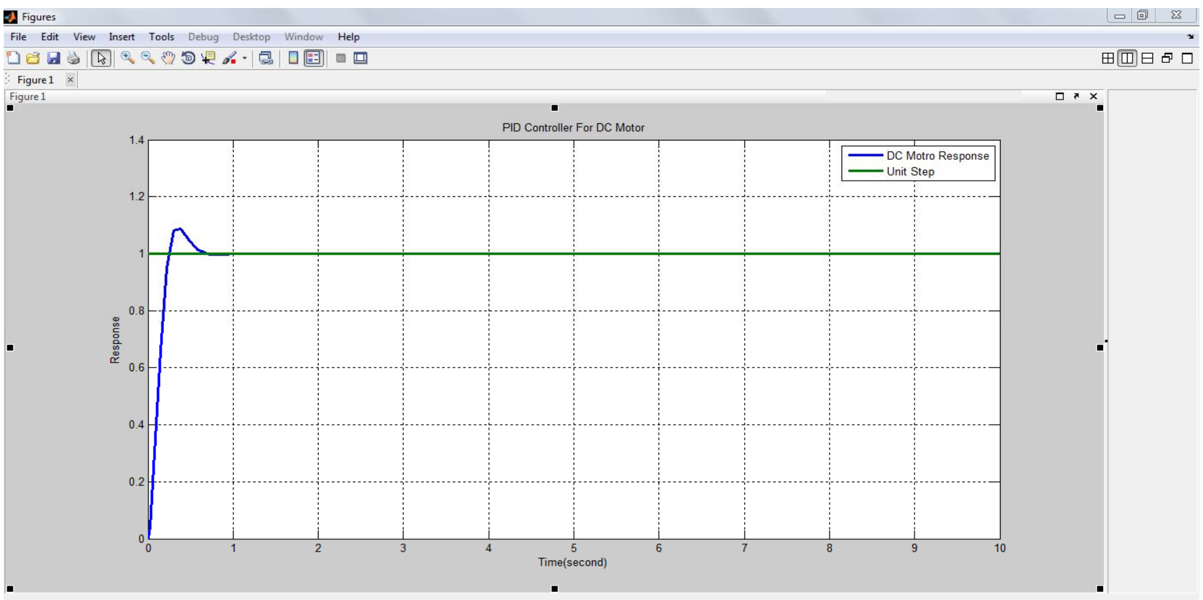

Figure 4.3: PID controlled DC motor response withoutdisturbance and load

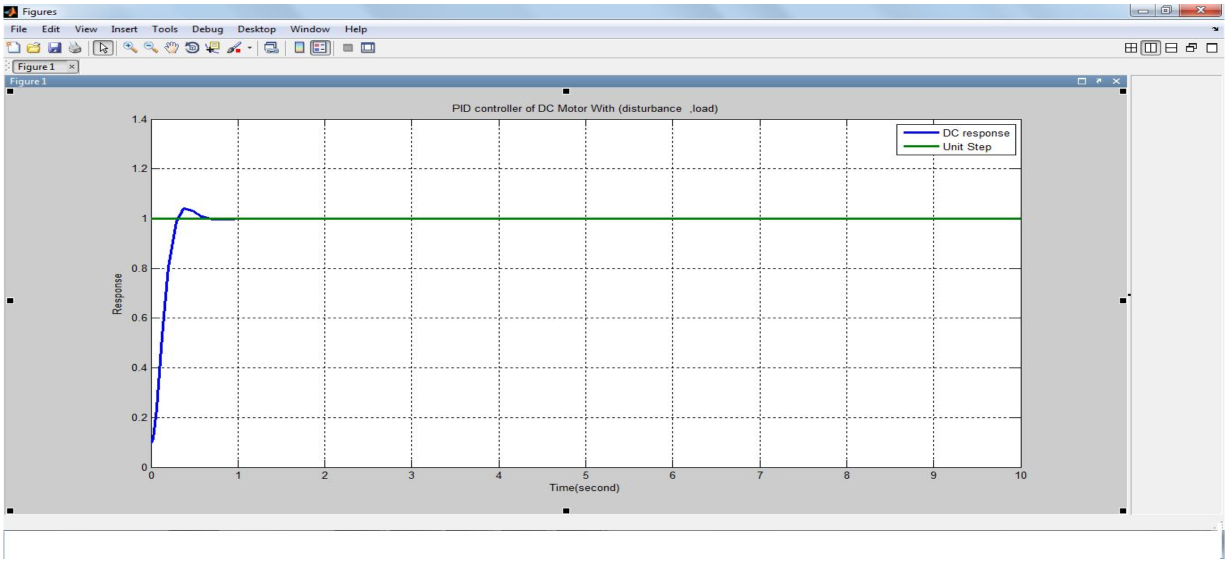

Figure 4.4: PID controlled DC motor response withdisturbance and load

Table 4.1:PID Parameters

Kc	Ki	Kd
0.2311	6.1553	.00012

4.4Simulation Result of DC Motor with MRAC

Figures (4.5) to (4.6) show the simulation of DC motor with MRAC in case of without and with load. In simulation, the constants gammas were grouped in one set as γ_P = 0.8,γ_i = 4 and γ_d = 2.4.

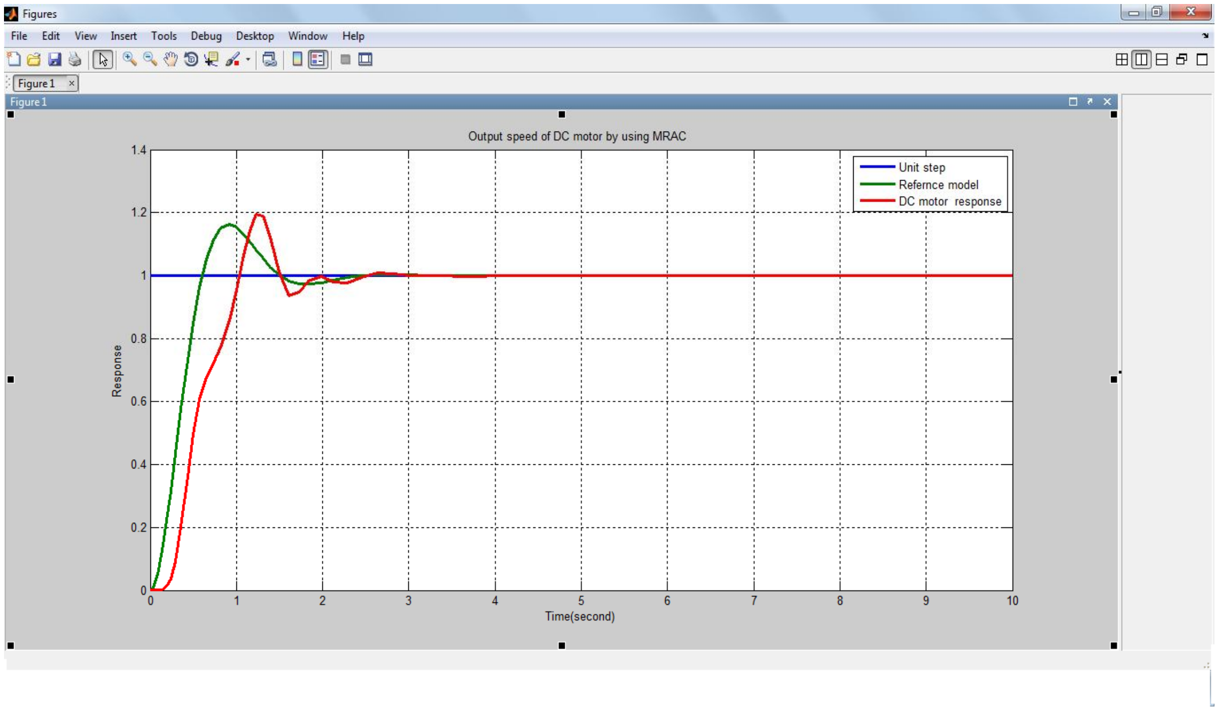

Figure 4.5: MRAC controlled DC motor response withoutload and disturbance

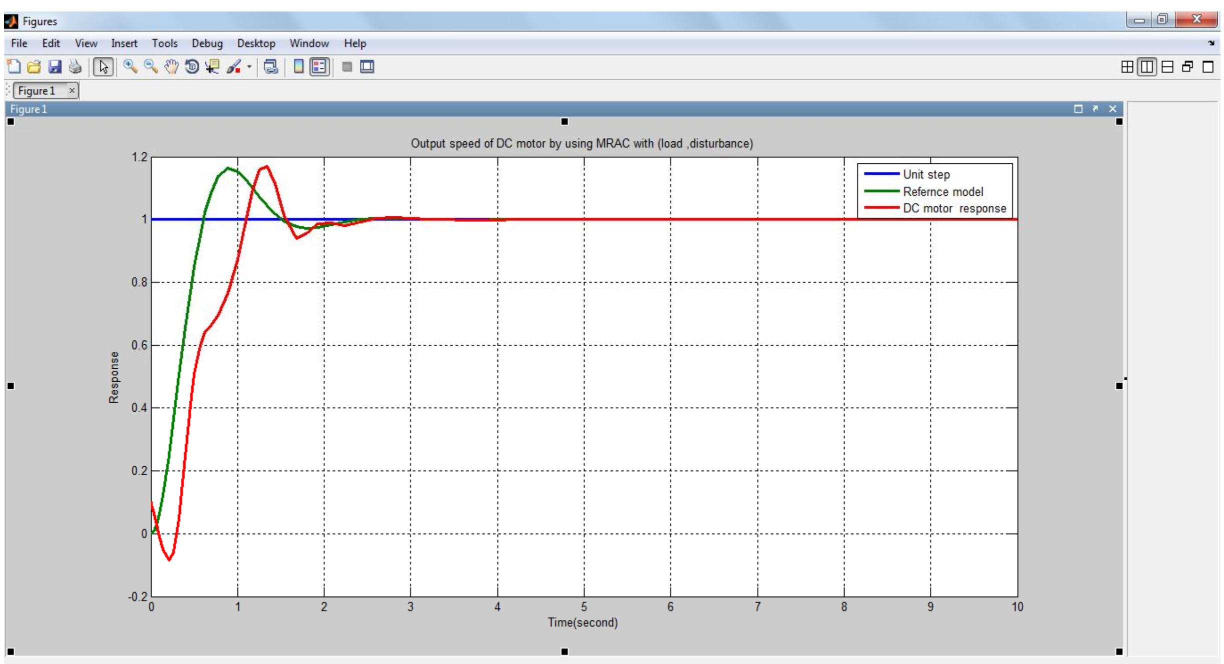

Figure 4.6: MRAC controlled DC motor response with load and disturbance

4.5Simulation Result of DC Motor with Fuzzy Controller

Figure (4.7) shows performance of the Fuzzy PD controller on DC motor without(loaddisturbance) condition the results show that fuzzy PD controller reach settling time is 2.877 sec. While figure (4.8) shown the performance of the DC Motor by using PD fuzzy controller with (load,disturbance) and the result show that the system reaching time is 3.08. Sec.

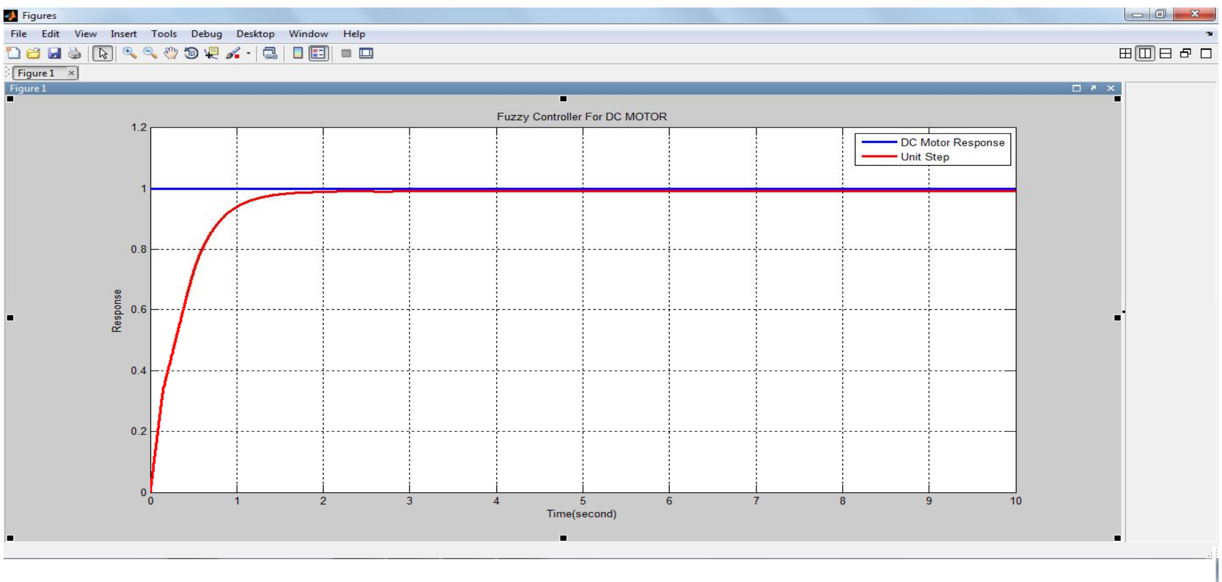

Figure 4.7: PD fuzzy controlled DC motor response controller without load and disturbance

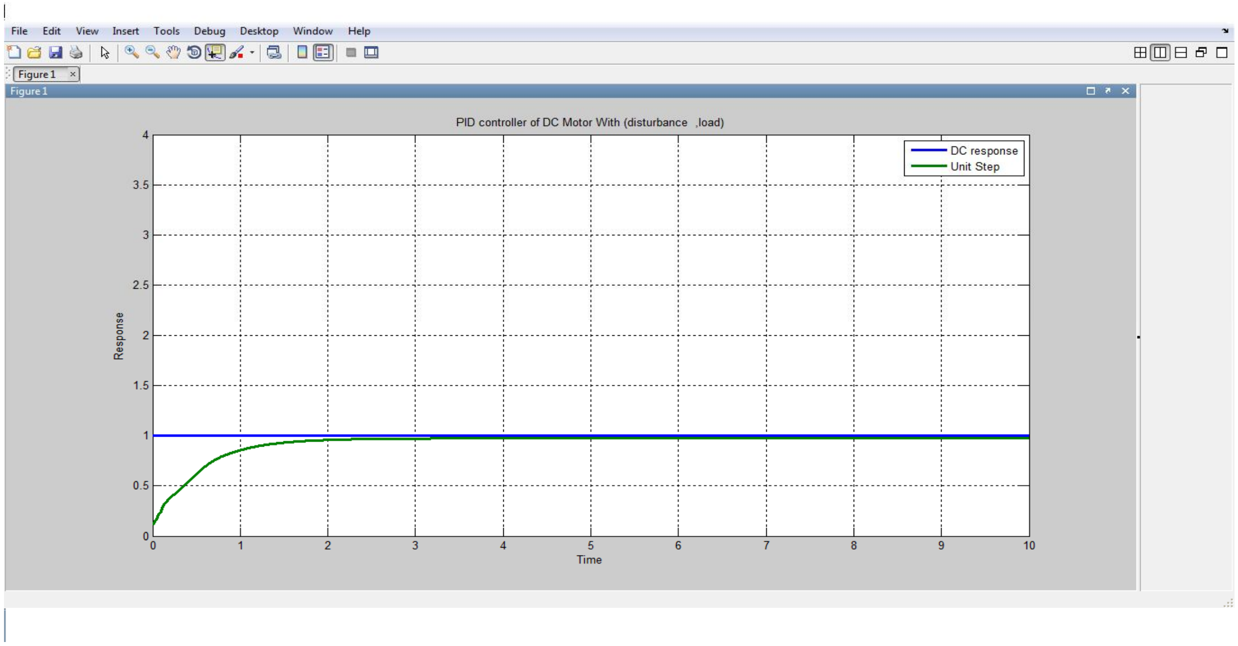

Figure 4.8: PD fuzzy controlled DC motor response controller with load and disturbance

4.6 Simulation Result of DC Motor with MRFAC

For the DC motor plant , the performance of MRFAC , which described in chapter three is shown in the Figure (4.9) to Figure (4.10) that represents the speed response of DC motorwithout and with (disturbance , load) .

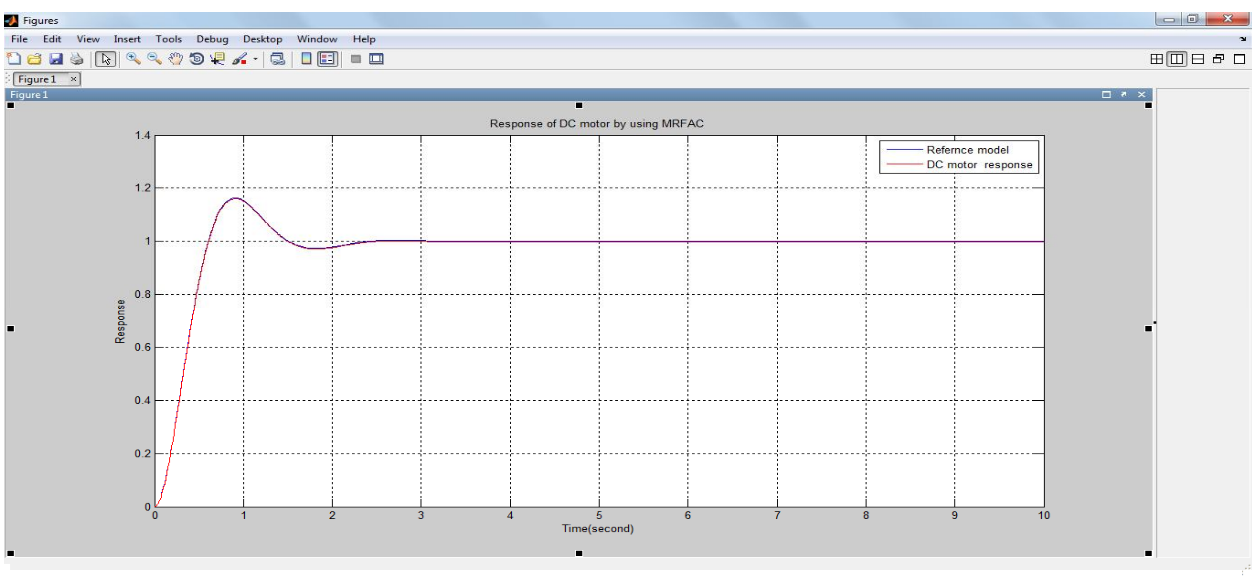

Figure 4.9: MRFAC controlled DC response without load and disturbance

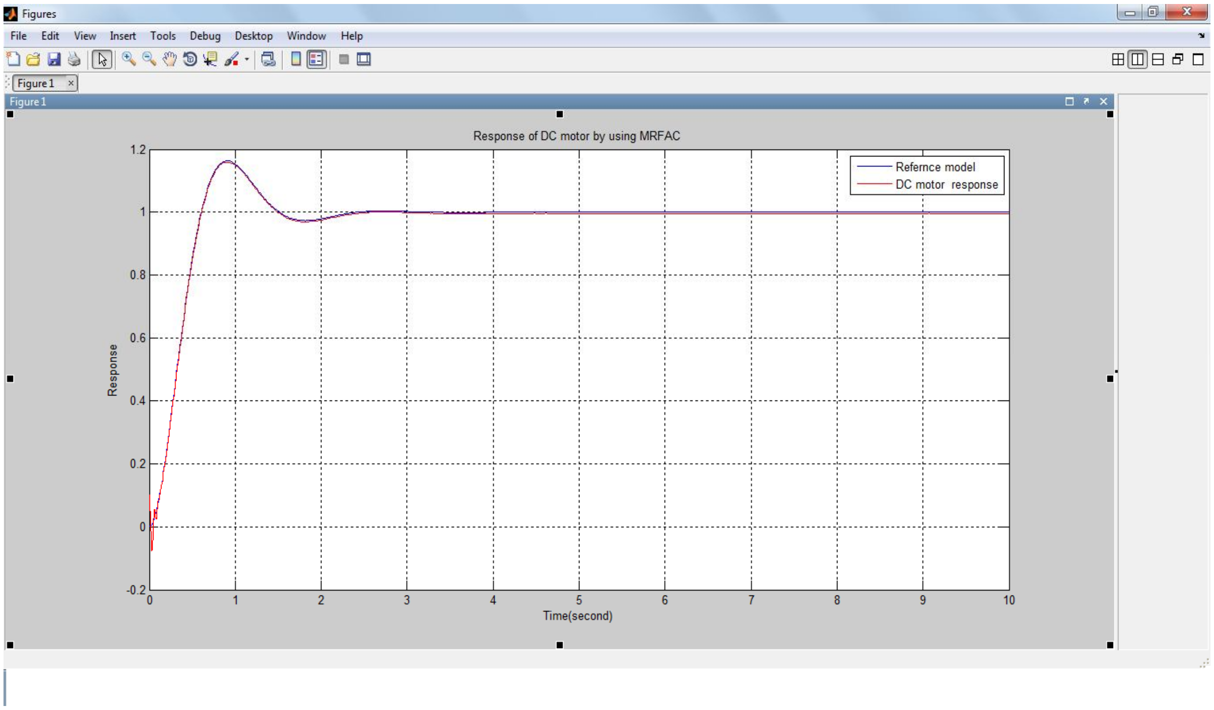

Figure 4.10: MRFAC controlled DC response with load and disturbance

4.7 Comparisons and Discussions

Nonadoptive control means the classic control methods that which uses a constant quantity as the reference quantity instead of using a function as the reference model. In nonadoptive control, controller parameters are constant during process, against adaptive control. At motor drive time by this method, the error is so big, then vibrations amortized and the motor output approaches reference quantity.

By reviewing results obtained from a number of experimental methods which includes open loop response , classical PID controllers and PD Fuzzy logic control using SIMULINK MATLAB and comparing between MRAC and MRFAC .Table 4-2 to 4-3 shown the specification comparison between uncontrolled , PID controller and PD Fuzzy controller , with and without disturbances . Also table (4.4)to (4.5) show the comparison between MRAC and MRFAC with and without disturbances .The reference input is a unit step, figure (4.1) and (4.2) show the uncontrolled systemresponse without and with (load,disturbance), the output speed is poor with large overshoot and reduced start up time delay and rise time as shown in table (4.2) and (4.3).

The speed response of DC motor using PID controller without and with (load,disturbance) are shown in figure (4.3) and (4.4), the PID controller reduced the overshoot,also the rise and settling time are still have small startuptime.

Figure (4.7) and (4.8) show the response of DC motor using PD fuzzy controller without and with (load,disturbance), the figure show that the PD fuzzy controller performing well, eliminating the overshoot. The performance of PD fuzzy controller is observed to be better than the conventional PID controller as the proposed controller results in smaller overshoot in the system.

The MRAC and proposed MRFAC controller scheme have been simulated and the results are displayed in Figures (4.5) to (4- 6) and Figure (4.9) to (4.10). The simulation results clearly show that the MRFAC controller possesses minimal overshoot and exhibits faster response as compared to the MRAC. Figure (4.5) and (4.6) show that there are difference between reference model and the system output due to the difficulties in adaptation gain parameters γ_P , γ_i and γ_d . The main weakness of the standard MRAC, with MIT rule, is non-existent clearly defined rules for the adaptation gain selection. In most cases, however, it is chosen based on the large number of simulations and trial and error methods.

The Fuzzy logic Model Reference Adaptive Control (MRFAC) maintains satisfactory response irrespective of the magnitude of the inputs. It enhances the performance of the DC drive compared to conventional MRAC.

Table 4.2: Specification of DC motor without (load,disturbance)

Specification	Open Loop	PID	PD Fuzzy
Rise Time (second)	0.805	0.219	2.03
Settling Time (second)	2.06	0.72	2.87

Overshoot MP (%)	-	8.8%	0

Table 4.3: Specification of DC motor with (load,disturbance)

Specification	Open Loop	PID	PD Fuzzy
Rise Time (second)	0.046	0.289	3.08
Settling Time (second)	2.007	0.7167	3.233
Overshoot MP (%)	-	4.2%	0

Table 4.4:specification of DC Motor for MRAC and MRFAC without (load, disturbance)

Specification	MRAC	MRFAC
Rise Time (second)	0.954	0.51
Settling Time (second)	3.007	2.76
Overshoot MP (%)	19.5%	16.01%

Table 4.5: specification of DC Motor for MRAC and MRFAC with (load,disturbance)

Specification	MRAC	MRFAC
Rise Time (second)	1.084	0.456
Settling Time (second)	3.005	2.156
Overshoot MP (%)	16.9%	15.9%

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The DC motor has been reviewed in this study from perspective of control theory. A DC motor is controlled using convention methods such as a PID controller and PD Fuzzy controller.

The performance parameters are examined for the convention DC motor, the parameters have been used as reference to assess the enhancements introduced when using classical MRAC.The study is based on the mathematical models of DC motor and on the MATLAB SIMULINK software platform. The speed response has been simulated for two cases when the DC motor is with and without load and disturbances.

The study basically exhibits versatility of high performance MRFAC, hence the implementation of the fuzzy controller is a very cost effective solution to the drive control design. Furthermore the MRFAC enhances the performance of the drive system .the simulation results show that the error tends to zero whenever a load disturbance or supply voltage variation is introduced. To improve the model-following performance, the feed-forward type MRFAC is designed to keep the equilibrium state on the reference model.

The feed-forward type MRFAC is simple in structure , fast in convergence ,and better in performance .Thought MRFAC is derived for the linear plant on the equilibrium state with some approximations , it tolerates much larger model-plant mismatch due to inherent nonlinear feature of Fuzzy logic controller .Successful simulations demonstrate that MRFAC can achieve more robust performance than MRAC

5.2 Recommendations

Use of wide range of adjustable speed drive operation.

Study implementation using neuro-fuzzy MRAC.

PID controller can be used in order to control the specifications of the model reference.

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