SIMULATION STUDIES ON HYBRID FUZZY-PI CONTROLLERS FOR DC MOTOR CONTROL

A Dissertation Submitted towards the partial fulfillment of the requirement for the award of the degree of

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Submitted by
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CERTIFICATE

It is certified that **Ms. NIDHI KAUSHIK** Roll No**. 10705**, student of Master of Engineering, Control and Instrumentation, Department of Electrical Engineering, Delhi College of Engineering, has submitted the major project thesis entitled **"SIMULATION STUDIES ON HYBRID FUZZY-PI CONTROLLERS FOR D.C. MOTOR CONTROL"**, under my guidance towards partial fulfilment of the requirement for the award of the degree of Master of Engineering (Control & Instrumentation).

This dissertation is a bonafide record of work carried out by her under my guidance and supervision. The matter embodied in this thesis has not been submitted to any university or institute for award of any degree.

I wish her success in all her endeavors.

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ABSTRACT

DC motors are widely used in industry for their high reliability and low cost. It is desirable that the motor speed be controlled within a given specifications under various known or unknown disturbances. DC motors are extensively used in robotics, actuators and electrical equipment. Therefore, the control of the position or/and speed of a DC motor is an important issue and has been studied since the early decades in the last century. Extensive use of DC motors is due to their controllability of speed and their compatibility with the new digital system sets. Electric motors use a significant percentage of the electrical energy and even small improvement in operating efficiency could result in large reduction in consumption of energy. New techniques are therefore required to extract the ultimate performance from these motors/drives. In recent times, fuzzy control has emerged as one of the most attractive non linear controller for research and applications in the realm of industrial processes. Motor control by fuzzy logic controller is a promising technique for faster and reliable speed and position control. The objective of the fuzzy control is to design a system with acceptable performance characteristics over a wide range of uncertainty. The fuzzy control is basically nonlinear and adaptive in nature, giving robust performance in the face of parameter variation and load disturbance effects. In this work, in depth study has been done on conventional controllers, fuzzy controllers and hybrid controllers for controlling the speed of DC motors. The feasibility of such controller design is evaluated by simulation in the Matlab/Simulink environment. Different type of controllers are analyzed and compared – Proportional Integral controller, Fuzzy Logic controller, and Hybrid Fuzzy controller.

Dedicated simulation software like MATLAB with Simulink has been used for modeling and simulation purpose. The conventional speed controllers for motor control suffer from the problem of stability. Besides, these controllers show either steady state error (PD controller) or sluggish response (PI, PID). The fuzzy logic controller introduces noise at the set point but it has a very good transient performance. The drive response obtained using hybrid controller (series and parallel) are compared to the corresponding drive performance obtained using conventional controllers and fuzzy logic controller. The performance comparison of conventional Fuzzy Logic Controller with hybrid fuzzy PI type controller has been done in terms of several performance measures such as settling time, steady state error and rise time. In this dissertation PI, Fuzzy logic, and Hybrid Fuzzy controllers for control of a separately excited DC motor are considered and the system responses are compared when these controllers are applied to the system.

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LIST OF SYMBOLS

w_r	Reference speed.
K_p	Proportional gain constant.
K_i	Integral gain constant.
w_{re}	Speed error.
Δw_{re}	Change in speed error.
$w_{rl}*$	Pre-compensated reference speed signal
μ	Membership value function.
α	Output membership.
$p(m)$	Location of peak of membership function.
$w_{re(n)}$	Speed error at the n^{th} instant.
$w*_{r(n)}$	Reference speed at the n^{th} instant.
$w_{r(n)}$	Actual speed at the nth instant.
$T*$	Torque output from the controller.
$T*(n)$	Torque command output from the controller at the n^{th} instant.

Chapter I

CHAPTER – I

INTRODUCTION

1.1 GENERAL

DC motor is the most common choice if wide range of adjustable speed drive operation is specified. Of the three kinds of DC motors – series, shunt and separately excited DC motors, separately excited DC motors are most often used. Different speed can be obtained by changing the armature voltage and the field voltage. The significant feature of separately excited DC motor configuration is its ability to produce high starting torque at low speed. Although the conventional PID technique is widely used in DC motor speed and position control, it isn't suitable for the high performance cases, because of the low robustness of PID controller. The various new control techniques in order to improve the system performance are being studied.

A common actuator in control systems is the DC motor. It directly provides the rotary motion and, coupled with wheels or drums and cables, can provide transitional motion. DC motors are widely used in household items like fans and refrigerators; they are also used for electric vehicles like golf carts wheel chairs etc. DC motors have always been preferred for the variable speed requirements because the speed – torque relationship can be varied to any useful form. The main reason to use separately excited dc motor in variable speed drives is the simplicity in control as the armature and the field currents are electrically decoupled from each other. Although the induction motor is better than DC motor with respect to size, weight, rotor inertia, cost, efficiency but because of its non-linear nature the required control becomes complex. DC motors feature a speed, which can be controlled smoothly down to zero, immediately followed by the acceleration in the opposite direction without power circuit switching. DC motors respond quickly to changes in control signals due to the DC motor's high ratio of torque to inertia. With rapid developments in the field of the power electronics technology, there is a need for simple and economically feasible control techniques for the speed control of a DC motor.

Today variant applications require more and more features such as speed applications to multi purpose accessories, user friendly interfaces, and security features. Such new requirements can be achieved through a fuzzy logic approach. Nowadays, most of fuzzy-logic based controls are only limited to a complicated ranking management of user interfaces, sensors and actuators, corresponding to a slow software speed operation. Fuzzy Logic motor control is a promising technique for extracting maximum performance from modern motors. More efficient motors can significantly reduce energy consumption and help mitigate environmental problems such as acid rain and global warming. Today improved motor control has reached a point requiring either highly accurate simulation of the complex, non-linear system or an alternate mechanism for predicting and optimizing controlled motor system behavior. Fuzzy logic has been chosen here to fill the latter role.

The conventional PI controller is one of the most common approaches for speed control in industrial electric drives in general, because of its simplicity, and the clear relationship existing between its parameters and the system response specifications. However, the main drawback of the PI controllers is that its gain parameters may perform well under some operating conditions but not in case of all. In general, the involved processes are complex, time variant, with non linearity and model uncertainties. Moreover, for industrial and process applications requiring high performance, self tuning controllers based on adaptive and optimal control techniques, or artificial intelligence methods have been proposed in order to improve the control robustness. One of the most successful expert system techniques applied in a wide range of control applications has been fuzzy logic. It can be combined with conventional PI controller, to build a fuzzy self tuning controller. The fuzzy adaptation can be built via updating fuzzy rules, fuzzy set functions, or controller gains. Fuzzy control is based on fuzzy logic – a logical system which is much closer in spirit to human thinking and natural language than traditional logical systems. The fuzzy logic controller based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. While PI, PID controllers are widely used in industrial applications, they exhibit poor performance when applied to systems containing unknown nonlinearities, such as dead zones, saturation, and hysteresis. Here a fuzzy logic based hybrid approach is proposed for PI controllers. Classical control seeks to achieve a balanced trade off between multiple performance objectives using a single feedback function, whereas hybrid control seeks to achieve multiple performance objectives in a locally adaptive sense by switching between members of an a priori specified family of feedback functions. Hybrid controllers can be used to obtain improved closed-loop performance, beyond what can be achieved by using either classical linear or smooth nonlinear controllers. Motivation for hybrid control is the following: If the hybrid controller is appropriately defined, then the hybrid closed loop can reflect, to some degree, multiple performance properties associated with the closed-loop properties provided by each individual feedback function. This statement can be expressed in a slightly different way: motivation for use of hybrid control is that the performance of a hybrid closed loop can exceed the performance that can be achieved by any fixed feedback controller without switching.

In the present investigation, speed control of DC Motor has been realized by means of different types of controllers – Proportional Integral controller (PI), Fuzzy Logic controller (FL), and Hybrid Fuzzy controller. A comprehensive mathematical modeling of DC Motor drive with controllers have been carried out in MATLAB environment using Simulink. In this work, comparative study of response of these controllers has also been made.

1.2 CONCEPT OF CONTROLLERS

1.2.1 Proportional Controller

The Proportional, or, “P”, controller is the most basic controller. The control law is simple: control is directly proportional to error. Proportional control is the easiest feedback control to implement, and simple proportional control is probably the most common kind of control loop. A proportional controller is just the error signal multiplied by a constant and fed out to the drive. The chief shortcoming of the P-control law is that it allows DC offset error; it droops in the presence of fixed disturbances. Such disturbances are ubiquitous in controls: Ambient temperature drains heat, power supply loads draw DC current, and friction slows motion. DC offset error cannot be tolerated in many systems, but where it can, the modest P controller can suffice.

1.2.2 Proportional Integral Controller

With PI control, the P gain provides similar operation to that in the ‘P’ controller, and the ‘I’ gain provides DC stiffness. Larger ‘I’ gain provides more stiffness but also more overshoot. The primary shortcoming of the P controller, tolerance of DC error, is readily corrected by adding an integral gain to the control law. Because the integral will grow ever larger with even small DC offset error, any integral gain (other than zero) will eliminate DC offset droop. Integral control is used to add long-term precision to a control loop. The main drawback is that the PI controllers are more complicated to implement. Also, the saturation becomes more complicated. The PI controller lacks a windup function to control the integral value during saturation.

1.2.3 Proportional Derivative Controller

The P controller is augmented with a ‘D’ term to allow the higher proportional gain. The ‘D’ gain advances the phase of the loop by virtue of the 90 degree phase lead of a derivative. Using the ‘D’ gain will usually allow the system responsiveness to increase. The differential term is the last value of the position minus the current value of the position. This gives a rough estimate of these velocity (delta position/sample time), which predicts where the position will be in a while. The ‘PD’ controller is fast, powerful but more susceptible to stability problems, sampling irregularities, noise, and high frequency oscillations. Derivatives have high gain at high frequencies. So while some ‘D’ does help the phase margin, it affects the gain margin by adding gain at the phase crossover, typically at high frequency. Also, the derivative gain is sensitive to noise. In case of a differential element, the output is proportional to the position change divided by the sample time. If the position is changing at a constant rate but the sample time varies from sample to sample, noise will be observed. Since the differential gain is usually high, this noise will be amplified a great deal. Differential control suffers from noise problems because noise is usually spread relatively evenly across the frequency spectrum. Control commands and plant outputs, however, usually have most of their content at lower frequencies. Proportional control passes noise. Integral control averages its input signal, which tends to eliminate noise. Differential control enhances high frequency signals, so it enhances noise. The ‘D’ gain needs to be followed by a low pass filter to reduce the noise content.

1.2.4 Proportional Integral Derivative Controller

The PID controller adds differential gain to the PI controller. A PID controller is a two zone controller. The ‘I’ gain forms the low- frequency zone. The benefit of the ‘D’ gain is that it allows the ‘P’ gain to be set higher than it could be otherwise. The ‘P’ and ‘D’ gains together form the high-frequency zone. PID stands for "proportional, integral, derivative." These three terms describe the basic elements of a PID controller. Each of these elements performs a different task and has a different effect on the functioning of a system. In a typical PID controller these elements are driven by a combination of the system command and the feedback signal from the object that is being controlled (usually referred to as the "plant"). Their outputs are added together to form the system output

A PID controller provides faster response than a PI controller but is usually harder to control and more sensitive to changes in the plant model.

1.2.5 Fuzzy Logic Controller

Fuzzy logic, unlike the crispy logic in Boolean theory, deals with uncertain or imprecise situations. A variable in fuzzy logic has sets of values which are characterized by linguistic expressions, such as SMALL, MEDIUM, LARGE, etc. These linguistic expressions are represented numerically by fuzzy sets (sometimes referred to as fuzzy subsets). Every fuzzy set is characterized by a membership function, which varies from 0 to 1 (unlike 0 and 1 of a Boolean set). A fuzzy set has a distinct feature of allowing partial membership. In fact, a given element can be a member of a fuzzy set, with degree of membership varying from 0 (non-member) to 1 (full member), in contrast to a “crisp” or conventional set, where an element can either be or not be part of the set. Although fuzzy theory deals with imprecise information, it is based on sound quantitative mathematical theory. A fuzzy control algorithm for a process control system embeds the intuition and experience of an operator, designer and researcher. The control does not need accurate mathematical model of a plant, and therefore, it suits well to a process where the model is unknown or ill-defined. Fuzzy control algorithm can be refined by adaptation based on learning and fuzzy model of the plant. The fuzzy control also works well for complex nonlinear multi-dimensional system, system with parameter variation problem, or where the sensor signals are not precise.

The fuzzy logic speed controller has the internal structure of a knowledge based expert system. It requires a set of heuristic rules based upon the experience gained in the design of a conventional controller. The rules are expressed in terms of linguistic variables. The design of a fuzzy logic speed controller is based upon the error, and change in error. The internal structure of the fuzzy logic speed controller comprises of three functional blocks namely – the fuzzifier, the decision–maker and the defuzzifier. The fuzzifier converts crisp data into linguistic format. The decision maker decides in linguistic format with the help of logical linguistic rules supplied by the rule base and relevant data supplied by the data base. The output of the decision maker passes through the defuzzifier wherein the linguistic format signal is converted back into the numeric form or crisp form. The inputs are categorized as various linguistics variables with their corresponding membership values. Triangular membership distribution is used in the analysis and defuzzification is carried out by center of gravity method. The data flow in a fuzzy logic based system involves:-

(i) Fuzzification

Fuzzification means converting the crisp data to information represented by linguistic variables. The normalized error and change in error are fuzzified to overlapping fuzzy sets represented by linguistic variables in their respective universe of discourse. The change in control action is also fuzzified in its universe of discourse. The number of fuzzy sets, the membership functions, and the degree of overlapping depends on desired accuracy, response of the system, ease of implementation, upgradeability etc.

(ii) Rule – Base Evaluation

The knowledge base of a fuzzy logic based system contains a set of rules to define the response of the controller to various values of the input variables. Normally, the number of rules is equal to the product of the number of fuzzy sets in the input variables. The rules have the form of "IF – THEN" statements. The "IF" side of the rules contains one or more conditions called "antecedents" and the " THEN" side of rules contains on or more actions called "consequences". The response of the controller to input conditions is determined by processing the rule base module. The antecedents of a rule correspond directly to the degree of membership calculated during the fuzzification process. The strength of a rule is computed based on antecedent's values and then assigned to the rule's fuzzy action part. Normally minimum function is used. As a result , the value of the least true antecedent is assigned as the strength of the rule. When more than one rule is applied to the same action , the common practice is to use the highest strength rule.

(iii) Deffuzification

The response of the controller should be non fuzzy in nature. This module defuzzifies the response after the evaluation of the rule base module. Normally , the weighted average method is used for defuzzification.

1.2.6 Hybrid Fuzzy Controller

A major limitation of fuzzy control is the lack of a systematic methodology for developing fuzzy rules. A set of fuzzy rules often needs to be manually adjusted on a trial-and error basis before it reaches the desired level of performance. This tuning process is non trivial and could be time consuming for a first time fuzzy logic controller developer. This limitation of fuzzy logic controller is related to a more general problem in a process control, namely that changes in the operating conditions of a process plant are difficult to predict and adjust for. Hence, it is desirable to develop an intelligent controller that can improve its performance based on its experience, and to adapt its response in relation to variations in the process dynamics. In addition to being able to adapt automatically to a new environment, a hybrid controller can further simplify the task of developing rules, for the designer only needs to come up with an initial set of rules which are roughly correct. The burden of manually tuning the rules is thus removed from the designers. If the output of a speed controller is a combination of outputs of two speed controllers (FL and PI), combined together as a weighted sum to eliminate certain disadvantages, then the resulting controller is referred as a hybrid controller. The combination pattern is defined on the basis of the speed error. While combining the outputs of a conventional PI controller and a FL controller, the combination pattern defines how the output of each of the speed controllers is to be combined. Hybrid Series controller refers to the advance alteration of the reference control signal (reference speed) in accordance with the system response (actual speed) to eliminate certain undesired features observed in the response, such as , overshoot , undershoot and steady state error. The processing occurs as follows:-

(i) Speed error and rate of change of speed error are calculated.

(ii) These two input signals are accepted by the FL controller as two input signals.

(iii) The output of the FL controller is added with the reference speed signal so as to generate a modified reference speed signal.

This modified speed signal is used by the remaining PI control strategy.

Hybrid controllers provide a generalization of classical feedback controllers for linear and nonlinear systems. The performance benefits of hybrid controllers include -

- Performance that exceeds any fixed classical linear or nonlinear smooth controller;
- Performance that reflects multiple objectives such as response speed, accuracy, optimality, robustness, and disturbance attenuation;
- Performance that respects state and control constraints.

Classical control seeks to achieve a balanced trade off between multiple performance objectives using a single feedback function, whereas hybrid control seeks to achieve multiple performance objectives in a locally adaptive sense by switching between members of a priori specified family of feedback functions. Hybrid controllers can be used to obtain improved closed-loop performance, beyond what can be achieved by using either classical linear or smooth nonlinear controllers. Motivation for hybrid control is the following: If the hybrid controller is appropriately defined, then the hybrid closed loop can reflect, to some degree, multiple performance properties associated with the closed-loop properties provided by each individual feedback function. This statement can be expressed in a slightly different way: motivation for use of hybrid control is that the performance of a hybrid closed loop can exceed the performance that can be achieved by any fixed feedback controller without switching.

1.3 SCOPE OF WORK

In case of a separately excited DC Motor, where the control of field and torque being independent of each other, the dynamic performance can be improved to a great extent by choosing suitable controller. The present work comprises of comparison and analysis of various controllers for the speed control of a separately excited DC motor. With the advancements in the field of Power Electronics, providing fast and affordable voltage control, a straightforward speed control is available. The work identified for investigation in this thesis pertain chiefly to develop modeling in MATLAB/SIMULINK for DC motor drive and various range of conventional and fuzzy logic controllers to develop a hybrid controller for the DC drive and carry out a relative performance study.

1.4 OUTLINE OF CHAPTERS

The contents of the thesis have been divided into the following chapters:

Chapter I

It includes the importance, state of art and potential applications of the separately excited dc motor drive. It also covers the concept of various controllers along with scope of proposed research work.

Chapter II

This chapter deals with an exhaustive literature review on the different controllers. It relates to the developments in the closed loop speed controllers. It includes the state of art on speed control of dc motor. It also covers a review of literature on the P, PI, PD, PID, Fuzzy, Series Hybrid, and Parallel Hybrid controllers applied to various applications. It also states the significant developments in the field of motor control.

Chapter III

This chapter deals with the modeling and simulation of different controllers - PI, Fuzzy, and Hybrid Fuzzy. It includes the simulation of the drive for speed control. A comparative study of different closed loop controllers has been made in terms of settling time, rise time, steady state error.

Chapter IV

This chapter contains the main conclusions based on the investigations carried out on this work. It also enlists the scope of further investigations in the speed control of a separately excited dc motor.

Chapter II

CHAPTER II

LITERATURE SURVEY

2.1 GENERAL

The preceding chapter deals with a general overview of different controllers, various potential applications and the state of art as applied to separately excited DC motor. The present chapter covers a Literature review relating to various developments in the field of speed control of DC Motors. It includes review of closed loop speed controllers – Proportional, Proportional Integral, Proportional Derivative, Proportional Integral Derivative, Fuzzy logic, and Hybrid Fuzzy controllers for speed control of a separately excited dc motor. A review has also been carried out for the innovations in design of these controllers.

2.2 SIGNIFICANT DEVELOPMENTS

Artificial Intelligence is machine emulation of the human thinking processes. The term began to be systematically used since the Dartmouth College conference in 1956 when “artificial intelligence” was defined as “computer processes that attempt to emulate the human thought processes that are associated with activities that require the use of intelligence.” Human brain is the most complex machine on earth. For a long time, the neuro-biologists have been taking the bottom-up approach to understand the brain structure and its functioning, and the behavioral scientists, such as psychologists and psychiatrists, the top down approach to understand the human thinking process. However, our knowledge about the brain is so inadequate at present that it is expected to take another 50 to 100 years to understand the human brain and its thinking process. In early age, it was perceived that human brain takes decision on the basis of "yes-no" or "true-false" reasoning. In 1854, George Boole first published his article "Investigations on the laws of thought," and Boolean algebra and set theory were born as a result. Gradually, the advent of electronic logic and solid state IC's ushered the modem era of Von Neumann type digital computation. Digital computers were defined as "intelligent" machines because of their capability to process human thought - like yes (1) - no (0) logic. Of course, using the same binary logic, computers can solve complex scientific, engineering, and other data processing problems. Since the 1960's and in the early 1970's, it was felt that computers have severe limitations being able to handle only algorithmic-type problems. An entirely new way of structuring software that closely matches the human thinking process, called "Expert System" was born. The new branch of software engineering is called "Knowledge Engineering." This new breed of "Knowledge Engineers" was responsible for the acquisition of knowledge from the human experts in a particular domain and translating it into software. In the 1980's, expert system applications proliferated in industrial process control, medicine, geology, agriculture, information management, military science, and space technology, just to name a few. Since the mid 1960's, a new theory called "Fuzzy Logic" or fuzzy set theory was propounded which gradually helped to supplement the expert system as an AI tool. L. A.

Zadeh [3], the originator of this theory, argued that most of human thinking is fuzzy or imprecise in nature, and therefore, Boolean logic (which is represented by crisp "0" and "1") cannot adequately emulate the thinking process. However, the general methodology of reasoning remaining the same, it was defined as "fuzzy expert system." In recent years, fuzzy logic has emerged as an important AI tool to characterize and control a system whose model is not known, or ill-defined. Fuzzy logic deals with problems that are vague, uncertain, and indecisive in nature. It tends to mimic human thinking. In conventional set theory based on human logic, a particular object or variable is either a member (logic 1) of a given set or it is not (logic 0). In fuzzy set theory , a particular object has a degree of membership in a given set that may be anywhere in range of 0 (completely not in set) to 1 (completely in the set). This property helps fuzzy logic to deal with no statically uncertain situations in a fairly natural way.

From the available literature it is revealed that the use of various controllers for speed control of separately excited dc motor has become a popular method for enhancing the performance of the drive. The main advantage with the separately excited dc motor is the ease of control and better dynamic performance. Fuzzy logic motor control is a promising technique for extracting maximum performance from the modern motors. Fuzzy logic offers a convenient way of designing controller from experiences and knowledge about the process being controlled. This heuristic approach can enhance the performance , reliability, and robustness of the closed loop system more than the conventional controllers. Research has proved that a properly designed fuzzy controller can outer perform a conventional PID controller such that the overall performance can be substantially improved. A major limitation of fuzzy control is the lack of a systematic methodology for developing fuzzy rules. During the past few years, several approaches for developing self organizing fuzzy systems have been proposed[13]. These approaches use adaptation and learning techniques drawn from neural network theory and artificial intelligence. Dedicated simulation software like MATLAB with simulink and fuzzy logic toolbox has made the modeling and simulation of the system efficient and simple. The advancement in speed control techniques from a basic proportional control to fuzzy logic control has resulted in a remarkable improvement in the response of the drive. Elimination of steady state error, overshoot and oscillations has resulted in a better response. The recent advancement in the technology has led to the practical implementation of such control techniques in the real time.

2.3 LITERATURE REVIEW

Another aspect of research has been towards improvement in response of the drive. The quality of the response of the drive is generally defined through performance indices such as starting time, rise time, settling time and steady state error. The response of the drive is highly affected by the type of speed controller used in the control structure. The Proportional and Proportional Integral speed controller is considered as a basic controller among various speed controllers. Singh and Ahmed [8] have reported Fuzzy Logic control application in system control. A novel design using fuzzy logic control and phase-locked loop to obtain a DC motor speed control system with excellent regulation and high robustness has also been presented. The fuzzy logic controller is incorporated in order to achieve quick control of motor speed smoothly. The fuzzy logic controller enhances the robustness of the motor control system, which can handle abrupt load variation and exhibit good disturbance behavior. Alexandrovitz and Zabar [5] have presented a Thyristorized static switch used recently in dc motor speed control. DC motors are used in many applications such as steel rolling mills, electric trains, and robotic manipulators require speed controllers to perform tasks. Major problems in applying a conventional control algorithm in a speed controller are the effects of nonlinearity in a DC motor. The nonlinear characteristics of a DC motor such as saturation and friction could degrade the performance of conventional controllers**.** Many advanced model-based control methods such as variable-structure control and model reference adaptive control has been developed to reduce these effects. However, the performance of these methods depends on the accuracy of system models and parameters. Generally, an accurate non-linear model of an actual DC motor is difficult to find, and parameter values obtained from system identification may be only approximated values.

Emerging intelligent techniques have been developed and extensively used to improve or to replace conventional control techniques because these techniques do not require a precise model. One of intelligent techniques, fuzzy logic developed by Zadeh [4] is applied for controller design in many applications**.** A fuzzy logic (FL) controller has been proved analytically to be equivalent to a nonlinear PI controller when a nonlinear defuzzification method is used. Also, the results from the comparisons of conventional and fuzzy logic control techniques in the form of a FL Controller and fuzzy compensator have shown that the fuzzy logic can reduce the effects of nonlinearity in a DC motor and improve the performance of a controller. A Fuzzy Logic Controller has been implemented on many platforms such as digital signal processor**,** or off-the shelf microcontroller**.** These platforms have different advantages and disadvantages. The Fuzzy Logic Controller developed on DSP or PC can quickly process fuzzy computation to generate control efforts, but the physical size of the system may become too big and quite expensive for a small DC motor application.

On the other hands, using an off-the-shelf microcontroller[11] to implement a Fuzzy Logic Controller is **i**nexpensive and the physical size of the system is small, but the Fuzzy Logic Controller requires longer processing time. One way to improve the response time in microcontroller implementation approach is to use a lookup table, but this method needs much more memory to store a table. Since E.H. Mamdani introduced the concept of fuzzy logic control in 1974[12], which was strongly motivated by the theory of fuzzy sets developed by L.A.Zadeh [3], [4]. Fuzzy logic controller based systems have proven to be superior in performance to conventional systems in areas such as process control, automatic train operation systems, automatic crane operation systems, elevator control, automobile transmission control, and nuclear reactor control. Examples of successful FLC applications in industrial processes include heat exchange, warm water processes, activated sludge processes , cement kiln operation, water purification processes, and power systems operation. More recently, advances in computer hardware , technology supporting fuzzy control (e.g. fuzzy VLSI chips) have resulted in numerous commercial FLC applications in Japanese products such as washing machines, vacuum cleaners, air conditioners, and camcoders.

Compared to conventional techniques, Fuzzy Logic Controller offers three important benefits. First, developing a Fuzzy Logic Controller is cheaper than developing a model-based or other controller with equivalent performance. Second, Fuzzy Logic Controller's are more robust than PID control because they can cover a much wider range of operating conditions than a PID can. Third, Fuzzy Logic Controller's are customizable, since it is easier to understand and modify their rules, which not only mimic a human operator's strategies, but also are expressed in linguistic terms used in natural language. Fuzzy control has found wide acceptance in the recent years and the literature in this area is continuously expanding with many emerging new applications. The key advantages of fuzzy control are performance robustness against plant parameter variation and load disturbance effects, independence of mathematical model information of the plant, and satisfactory performance with imprecision signals from the sensors. The design of fuzzy controller essentially consists of knowledge base design that includes formulation of membership function (MF) shape and its distribution for the fuzzy variables, and the rule matrix design. It can be shown that MF's play important role in the performance of fuzzy control system. It is well-known that fuzzy control design essentially embeds the behavioral nature of the plant that is evidenced by the experience and intuition of a plant operator, and sometimes those of a designer and/or researcher of the plant. Therefore, fuzzy controller design is somewhat heuristic, i.e., depends on trial-and-error procedure. Unfortunately, optimal design of fuzzy controller by such heuristic procedure may become time consuming. A major limitation of fuzzy control is the lack of systematical methodology for developing fuzzy rules. A set of fuzzy rules often needs to be manually adjusted on a trial-and-error basis before it reaches the desired level of performance. This tuning process is non-trivial, and could be time consuming for a first time Fuzzy Logic Controller developer. This limitation of Fuzzy Logic Controller is related to a more general problem in process control, namely, that changes in operating conditions of a process plant are difficult to predict and adjust for. Hence, it is desirable to develop an intelligent controller that can improve its performance based on its experience, and to adapt its response in relation to variations in the process dynamics. In addition to being able to adapt automatically to a new operating environment, a self organizing fuzzy controller can further simplify the task of developing rules , for the designer only needs to come up with an initial set of rules which are roughly correct. The burden of manually tuning the controllers is thus removed from the designers.

Hybrid feedback control for linear and nonlinear control systems provides maximal flexibility for achieving multiple performance objectives; is consistent with computer based implementations. One of the key decisions in construction of any hybrid controller is the decision regarding the family of allowable feedback functions on which the hybrid controller is based. This decision is problem dependent, and it depends on the closed-loop performance objectives Finally, we mention that hybrid control or logic-based switching control has been extensively utilized in practical engineering control systems since the earliest days of computer control systems. In most cases, these control applications were not based on any hybrid control design theory, but they often proved successful in achieving practical control performance objectives. In this sense, there has been a significant gap between hybrid control practice and hybrid control theory, with the practical side often in advance of what could be explained or justified by the existing theory. Now, as important advances are being made in the theoretical aspects of hybrid control design, it is hoped that these advances can begin to influence the practice of hybrid control engineering and can also provide new concepts for treating previously intractable control problems. Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system. A model is not needed to develop a fuzzy controller, and this is the main advantage of the approach . Fuzzy control system has good robustness which can restrain influence of disturbance and fluctuation of parameters effectively, so it can make more excellent performance than conventional PI/PID controller, especially for the system with nonlinear, large time delay and time-varying.

In related work, Yasuda [16] described a method to suppress process overshoot using fuzzy expert control technique embedded in a PI controller. Their implementation although different, is also based on the approach of modifying the controller internal set point so that the plant stays on a desired response curve with minimal overshoot. In [17], Matsunaga and Kawaji used a "Hybrid" scheme for controlling a dc servomotor. In their scheme, the controller switches between fuzzy controller and a PD controller depending on whether the system is in transience or in steady state, respectively.

2.4 CONCLUSION

The exhaustive literature review has revealed that research work carried out on speed control of dc motor with different controllers is largely influenced by the technical developments in power electronics, microelectronics and control systems. Most of the developments in these fields are in the direction of increasing the robustness of the system and reducing the control hardware for the drive system. Therefore these developments improve the motor speed control to a stage where the motor can be used extensively in various applications. The main motivation is based on the desire to improve the performance of controllers under nonlinearities. Fuzzy logic methods can be used effectively to complement conventional control methods for improving performance and robustness, especially in the presence of unknown and severe nonlinearities.

Chapter III

CHAPTER III

MODELING OF DRIVE SYSTEM

3.1 GENERAL

The concept and types of various controllers under study, applications of dc motors and an exhaustive literature review have been covered in the preceding chapters. The present chapter deals with the modeling and simulation of the system – Speed controllers comprising of, Proportional Integral Controller, Fuzzy Logic Controller, Hybrid Fuzzy Controller, and Separately excited DC motor under different operating conditions in the environment of MATLAB with Simulink.

3.2 MODELLING OF SYSTEM

Each component of the Drive system is modeled by a set of mathematical equations. Such sets of equations when combined together represent the mathematical model of the complete system. The modeling of the different components of the drive system is described as follows:

3.2.1 Speed Controllers

Seven different types of controllers have been considered for speed control of a separately excited dc motor. The speed error (w_{re}) is computed and used as an input to the speed controller. The output is fed to the converter block which makes the current continuous in nature and outputs the terminal voltage which is supplied to the motor. The speed error at the nth instant of time is given as:

$w_{re(n)} = w^*_{r(n)} - w_{r(n)}$ (3.1)

where,

$w^*_{r(n)}$ is the reference speed at the n^{th} instant,

$w_{r(n)}$ rotor speed at n^{th} instant ,

and $w_{re(n)}$ speed error at the n^{th} instant.

3.2.1.1 Proportional Integral (PI) Controller

Fig 3.1 shows the general schematic block diagram of a PI Controller. The output of the speed controller at the n^{th} instant is given as:

$T(t) = K_p\, e(t) + K_i \square\, e(t)\, dt$ continuous domain (3.2)

$T_{(n)} = T^*_{(n-1)} + Kp\{w_{re(n)} - w_{re(n-1)}\} + K_i\, w_{re(n)}$ discrete domain (3.3)

where Kp and K_i are the proportional and integral gain parameters of the PI speed controller. The gain parameters are judicially selected by observing their effects on the response of the drive. Numerical values of the controller gains are given in the Appendix-I for the motor drive systems used in this investigation.

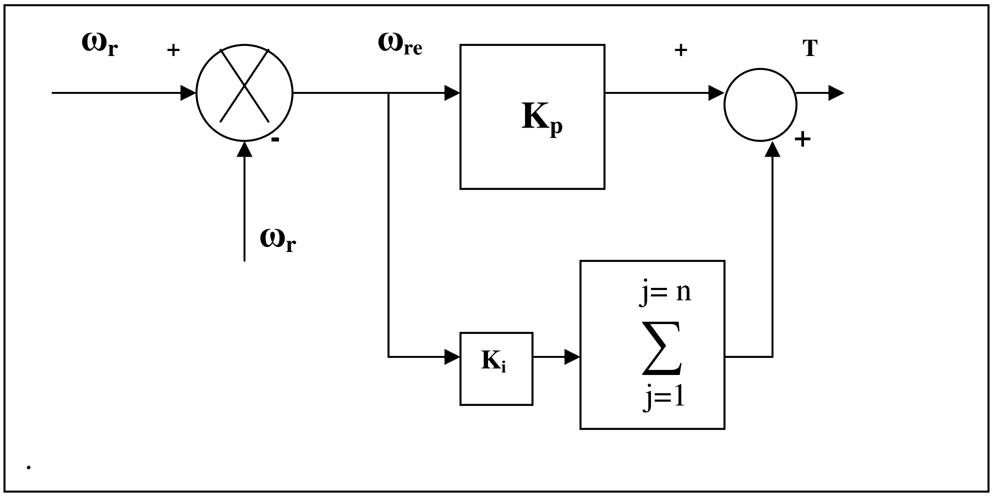

Fig 3.1 General Schematic block diagram of a Proportional Integral controller

3.2.1.2 Fuzzy Logic Controller

The internal structure of the Fuzzy logic speed controller is as shown in Fig 3.5. It comprises of three functional blocks namely - the fuzzifier , the decision – maker , and the defuzzifier . The necessary inputs are applied to these blocks by the rule based and data based blocks. The fuzzifier converts crisp data into linguistic format. The decision maker decides in linguistic format with the help of logical linguistic rules supplied by the rule base and relevant data supplied by the data base. The output of the decision maker passes through the defuzzifier wherein the linguistic format signal is converted back into the numeric form or crisp form. The decision making block uses the rules in the format of “ If – Then – Else”.

Fuzzy logic controllers have three significant advantages over conventional techniques – they are cheaper to develop, they cover a wide range of operating conditions (i.e. are more robust), and they are more readily customizable in natural language.

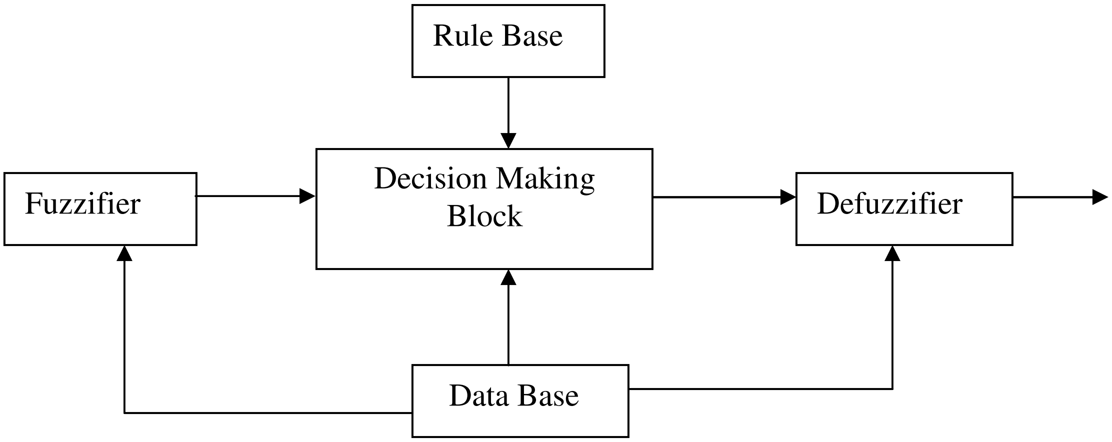

Fig 3.2 Schematic Block Diagram for Fuzzy Logic (FL) speed Controller

In accordance to the fuzzy logic (FL) concept, the processing takes place as follows:

(i) Calculation of the nth instant values of the two input signals namely , speed error and rate of change in speed error .

(ii) Scaling of the two input signals namely , speed error and the change in speed error.

(iii) The scaled input signals are fed to the fuzzy logic controller.

(iv) The scaled crisp data is converted into linguistic format in accordance with the defines fuzzy sets .

(v) In accordance to the linguistic rules , value of the output signal is determined. The required rules and data are supplied by the rule base and the data base.

(vi) The Linguistic output data is converted back into crisp output data by application of the method of defuzzification as follows :

Given a combination of two inputs , the membership of the corresponding output is taken as minimum membership value of the two respective inputs. Mathematically ,

$$\alpha = \min[\mu(\text{input } 1), \mu(\text{input } 2)]$$

$$\text{Crisp value} = \{\sum p(m)\ \alpha\} / \sum \alpha$$

where μ refers to the membership value, the output membership is stored in α and (pm) refers to location of peak of membership function.

The crisp value obtained is re scaled back to get the controller output. The input membership functions are defined by taking into account the speed and the acceleration of the motor. The motor speed range is well covered with the seven membership functions – NB (Negative Big),NM(Negative Medium),NS(Negative Small), ZE(Zero),PS(Positive Small), PM(Positive Medium), PB(Positive Big). Table 3.1 shows the fuzzy controller's rules. They have been defined by the understanding of the behavior of the system. One can find rules maintaining speed error zero (steady state rules), rules that avoid motor speed overshoot and rules that provide rapid response to large error resulting from command change.

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

Table 3.1 Fuzzy rules for Fuzzy logic controller.

3.2.1.3 Hybrid Fuzzy speed controller

Fuzzy Logic control technique is generally opted when intelligence and fast dynamic response are among the prime requirements. The major disadvantage in this type of control logic is the presence of steady state speed error on load. To eliminate this disadvantage it is necessary to combine Fuzzy Logic control with another suitable control technique, which is capable of removing the disadvantage existing in Fuzzy Logic control. Therefore, a PI controller is used in combination with Fuzzy Logic such that at operating point the PI controller takes over eliminating the disadvantage of Fuzzy Logic controller. Similarly, when away from the operating point Fuzzy Logic controller dominates and eliminates the error due to PI controller such as occurrence of overshoot and undershoots in drive response. Such a speed controller where weighted combination of two controller outputs contributes to the net output is called hybrid controller.

Fig 3.3 shows the general schematic block diagram of a Hybrid Fuzzy Speed Controller. It comprises of a simple PI controller connected in series with a fuzzy logic controller. Due to simple structure and ease of application, the PI controller is generally used in implementation. To make the same control robust in nature so that it becomes independent of parameter variations as well as the problems of undershoot and overshoot occurrence, a pre-compensation using Fuzzy logic is used for the reference signal. As a result, depending upon the value of speed error (w_{re}) and change in speed error (Δw_{re}), the FL control (used for purpose of pre-compensation of the reference signal) produces a signal (u), which may be positive or negative in value. The algebraic addition of the FL controller output with the defined reference speed (w_r*) produces the pre-compensated reference speed (w_{rl}*)to be used as reference speed in the remaining control action of PI controller. Such a phenomenon of pre-compensation eliminates the possible disadvantages in the normal PI controller and introduces robustness to the control system.

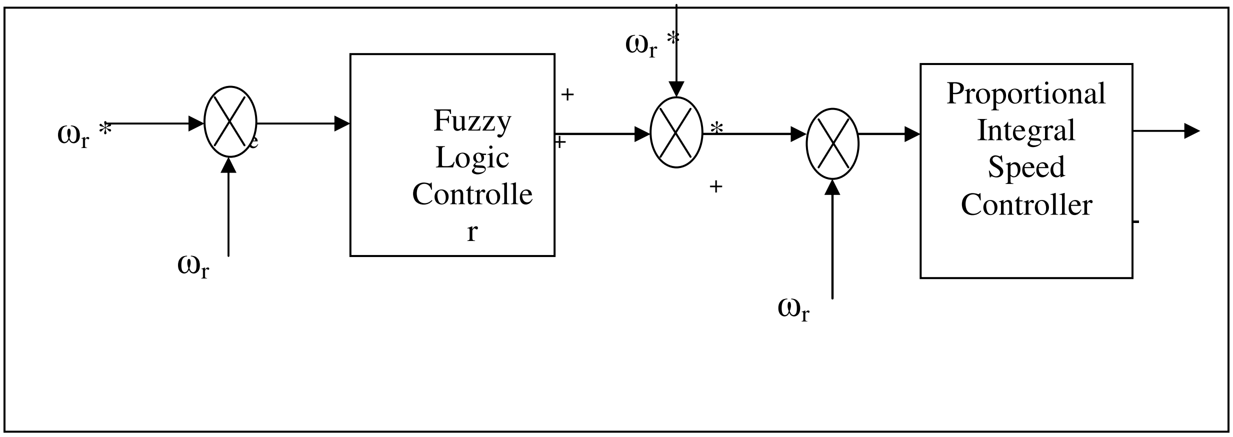

Fig 3.3 General schematic block diagram of a Hybrid Fuzzy controller.

The control algorithm processing takes place as follows:

(i) In the first step, speed error(w_{re}) and change of speed error (Δw_{re}) are calculated.

(ii) These two signals after being scaled to the proper range(pu) are used as input signals for the FL controller.

(iii) The output of the FL controller after proper re-scaling is algebraically added with the reference speed signal (w_r*) to generate pre-compensated reference speed signal (w_{rl}*).

The pre-compensated reference speed signal(w_{rl}) is used as reference speed in PI speed controller. The purpose of the fuzzy pre compensator is to modify the command signal to compensate for the overshoots and undershoots present in the output response when the plant has unknown non linearities. In addition, it provides fast response to the system. Table 3.2 shows the fuzzy rules for the series hybrid controller. The fuzzy sets for two inputs – Error {e(k)} , Change in Error{ Δe(k)}, and one Output variable - Speed { $y_p(k)$ } are defined by collection of seven linguistic values – NB, NM, NS, ZE, PS, PM, PB. The meaning of linguistic values is clear from the mnemonic: for example, NB stands for Negative Big, NM stands for Negative Medium, NS stands for Negative Small, ZE stands for Zero, and likewise for the positive (P) linguistic value. Associated with the term set of inputs and outputs is a collection of membership functions –

$$\mu = \{ \mu_{NB} , \mu_{NM} , \mu_{NS} , \mu_{ZE} , \mu_{PS} , \mu_{PM} , \mu_{PB} \}$$

Each membership function is a map from the real line to the interval[-1 1]. The membership functions are triangular type. The height of the membership functions is one. The realization of the function F[e(k),Δe(k)], based on the standard fuzzy method, consists of three stages : fuzzification, decision-making logic, and defuzzification.

(i) Fuzzification : The process of fuzzification transforms the inputs e(k) and Δe(k) into the setting of linguistic values. This consists of scaling the inputs e(k) and Δe(k) appropriately and then converting them into fuzzy sets.

(ii) Decision- Making process : Associated with the decision- making process is a set of fuzzy rules $R = \{R_1,R_2,\ldots,R_r\}$, where r is the total number of rules. The first two linguistic values are associated with the input variables e(k) and Δe(k) , while the third linguistic value is associated with the output. An example of the rule is the triplet (NS, PS , ZE). Rules are often written in the " IF – THEN – ELSE" format. For example , consider the rule represented by the triplet (ZE, NS , NM) , the idea in this rule is that if e(k) is zero and the Δe(k) is negative small than the output is negative medium. The set of rules used in the series hybrid controller are as shown in Table 3.2. There are 25 rules in altogether(i.e. r = 25) . The rules are derived by using a combination of experience , trial and error , and the knowledge of the response of the system. These are common approaches in the design of fuzzy logic rules, as described in [16].

(iii)Defuzzification: The defuzzification process maps the result of the fuzzy logic rule stage to a real number output F [e(k), Δe(k)]. We use the height defuzzification method which is simple to implement and gives relatively good results.

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

Table 3.2 Fuzzy rules for the Hybrid Fuzzy controller.

3.3 MATLAB SIMULATION

The simulation model has been developed in MATLAB environment along with simulink and fuzzy logic toolbox for simulating response of separately excited dc motor. The simulation environment in MATLAB/Simulink/fuzzy logic toolbox has become a standard tool in the research environment. This section of the chapter describes the model of separately excited dc motor developed in the MATLAB environment using the simulink. To test the versatility and reliability of the developed model, the speed control of dc motor has been initially simulated using conventional controller – Proportional Integral (PI). Then the drive performance has been compared using following speed controllers – Fuzzy logic controller, Hybrid Fuzzy controller, and finally the best control technique has been achieved.

3.3.1 Modeling using Simulink in MATLAB

In order to perform real time simulation of the drive system , the control structure is developed in MATLAB environment using SIMULINK. The main parts of the block diagram have been discussed in this section.

3.3.1.1 Speed Controllers

The model of speed controllers has been realized using the Simulink toolbox of the MATLAB software. The main function of the speed controller block is to provide a reference terminal voltage. The output of the speed controller is limited to a proper value in accordance to the motor rating by using a saturation block. The converter block converts the current in the same direction for proper functioning. The speed controllers realized using the simulink toolbox are namely, proportional integral speed controller, fuzzy logic speed controller, and hybrid fuzzy controller.

Fig 3.4 shows the matlab model block diagram for the PI controller. The basic operating equations have been stated in sub section 3.2.1.2. Using the proportional and integral gain parameters K_p and K_i respectively the desired motor speed control is achieved.

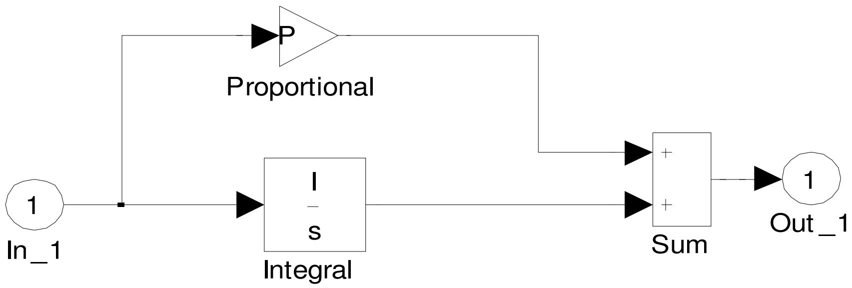

Fig 3.4 Matlab model block diagram for the PI controller

Fig 3.5 shows the matlab model diagram for the Fuzzy Logic speed controller. The two inputs namely, speed error and change in speed error are properly scaled and fed to the MATLAB fuzzy logic controller. The re-scaled defuzzified output of the fuzzy logic block after limiting forms the output of the controller block.

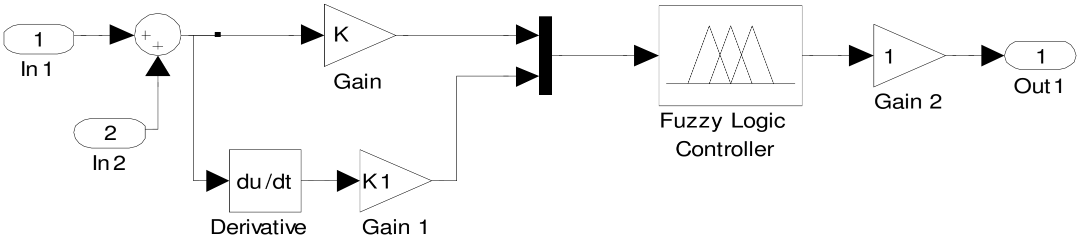

Fig 3.5 Matlab model block diagram for Fuzzy Logic controller

Fig 3.6 shows the matlab model diagram for the hybrid fuzzy speed controller. Such a controller combines the outputs of the Fuzzy logic and PI speed controller respectively as a weighted sum. The controller operation has been discussed in sub section 3.2.1.6. The

FL controller produces the modified reference speed signal, from which a speed error is calculated, which is fed to the PI speed controller as the reference speed signal.

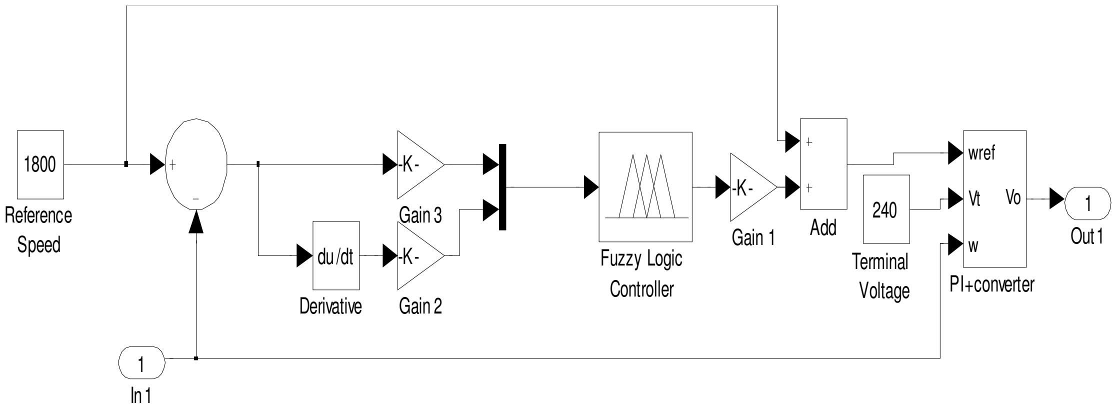

Fig 3.6 Matlab model diagram for the hybrid fuzzy controller

3.3.1.2 Separately excited DC motor

The simulation models have been developed in MATLAB environment along with SIMULINK. Simulink is an interactive tool for modeling, simulating, and analyzing dynamic ,multidomain systems. The MATLAB provides extensive tools for testing and debugging the desired system. This section of the chapter describes the model of separately excited DC motor developed in MATLAB environment. Fig 3.7 shows the matlab model block diagram for the separately excited DC motor. The inputs to the block are the modulated voltage, and the load torque. The outputs are the produced torque and the speed in revolutions per minute (rpm).

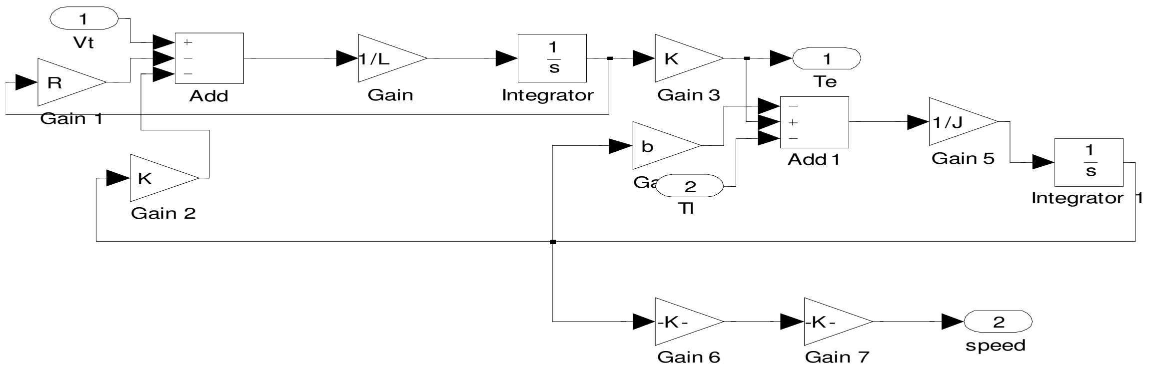

Fig 3.7 Matlab model diagram for the separately excited dc motor.

3.4 RESPONSE OF DRIVE USING DIFFERENT CONTROLLERS

3.4.1 Response of drive with PI Controller on Load

Fig 3.8 shows the Matlab figure diagram for the response of the dc drive with Proportional controller on load . The figure shows the plot for voltage, current, speed ,and torque of the motor on three conditions – no load, less than 50% load, and 70%load. The settling time at the reference speed 1800 rpm is observed as t= 0.6 sec. At t=1 sec, less than 50% load is applied and a dip is observed. At t= 2 sec, around 70% load is applied and the dip is observed to increase. From the response it is observed that the PI controller is not able to sustain the settled speed when the load is applied.

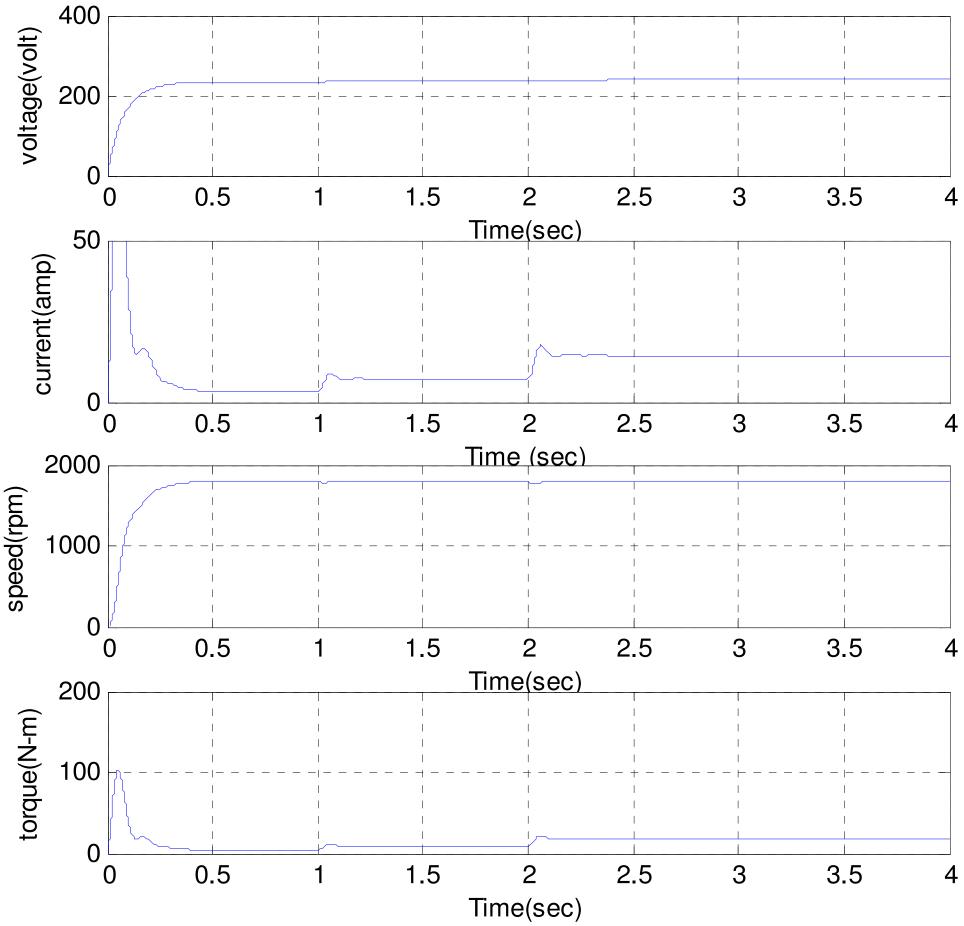

Fig 3.8 Matlab figure diagram for the response of the dc drive with Proportional Integral controller on load.

3.4.2 Response of drive with PI Controller on Speed Reversal

Fig 3.9 shows the Mat lab figure diagram for the response of the dc drive with Proportional controller on speed reversal. The figure shows the plot for voltage, current, speed and torque of the motor. At t=1 sec, switching is provided to the motor for speed reversal from 1800 rpm to -1800 rpm and at t= 2 sec, again the switching mechanism is turned ON for speed reversal from -1800 rpm to 1800 rpm. From the figure it is revealed that the motor takes substantial amount of time when switching from one speed to another. Similarly, Fig 3.10 shows the Matlab figure diagram when the speed reversal mechanism takes place from 1800 rpm to 1400 rpm

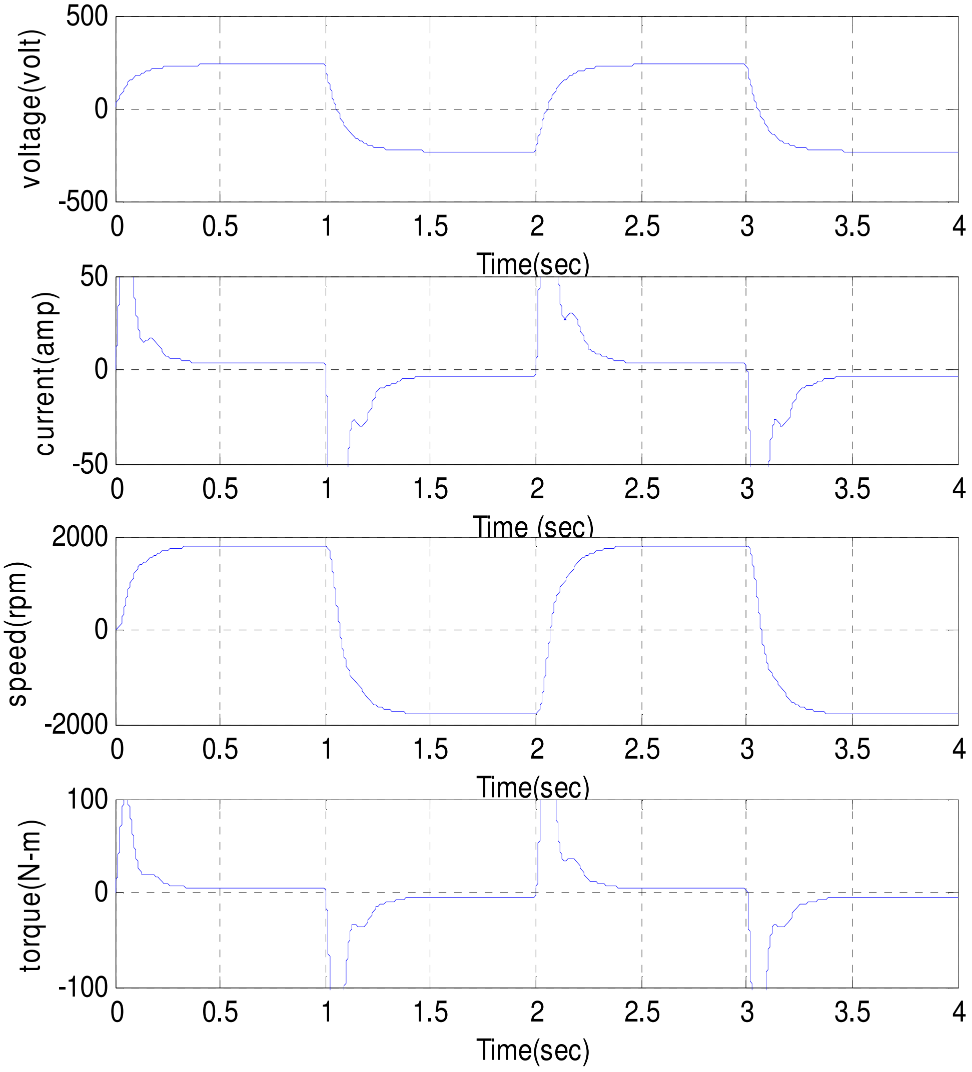

Fig 3.9 Matlab figure diagram for the response of the dc drive with Proportional Integral controller on speed reversal from 1800 rpm to -1800 rpm.

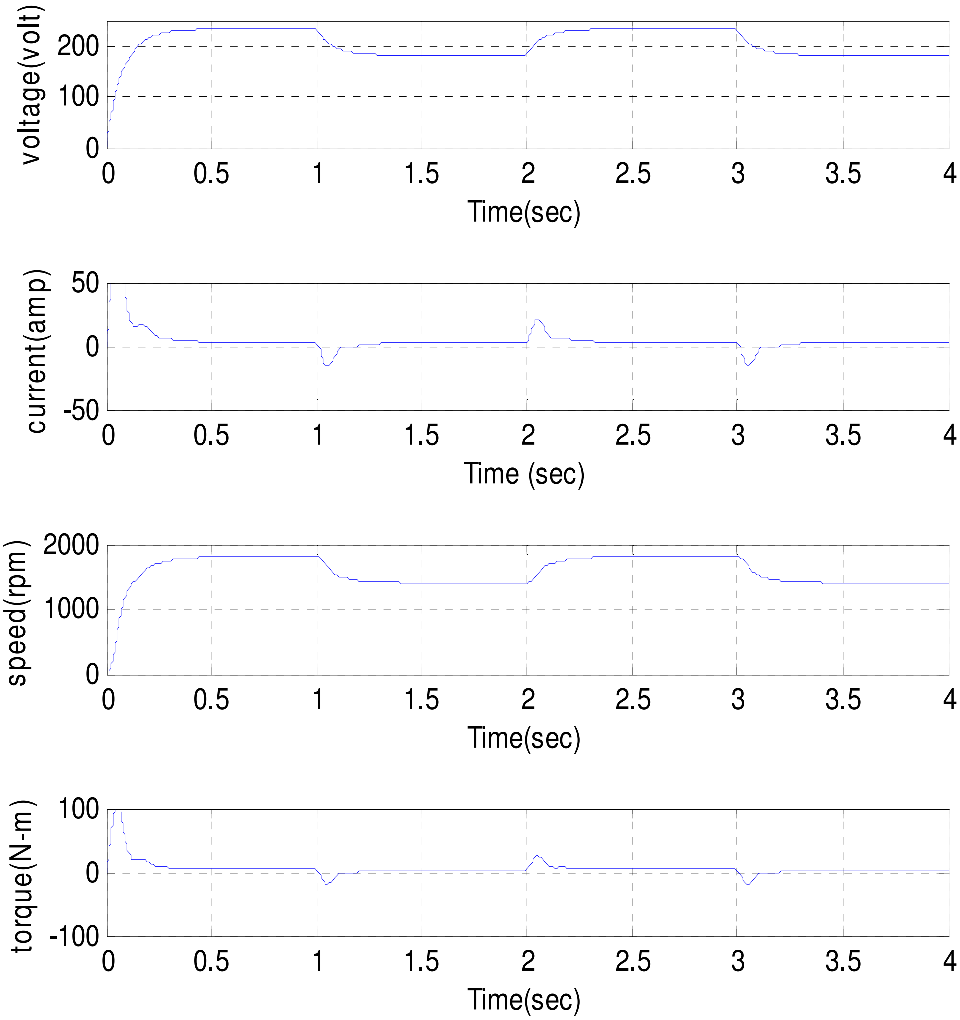

Fig 3.10 Matlab figure diagram for the response of the dc drive with Proportional Integral controller on speed reversal from 1800 rpm to 1400 rpm.

3.4.3 Response of drive with Fuzzy Logic Controller on Load.

Fig 3.11 shows the Matlab figure diagram for the response of the dc drive with Fuzzy Logic controller on load . The figure shows the plot for voltage, current, speed ,and torque of the motor. The settling time at the reference speed 1800 rpm is observed as t=

0.07 sec. However , steady state error is present which is because of the reason that the fuzzy logic controller introduces noise at the set point. At t=1 sec, less than 50% load is applied and at t= 2 sec, around 70% load is applied. No dip is observed in the speed on load application. From the response it is observed that the fuzzy logic controller is able to sustain the settled speed when the load is applied but at the cost of presence of steady state error.

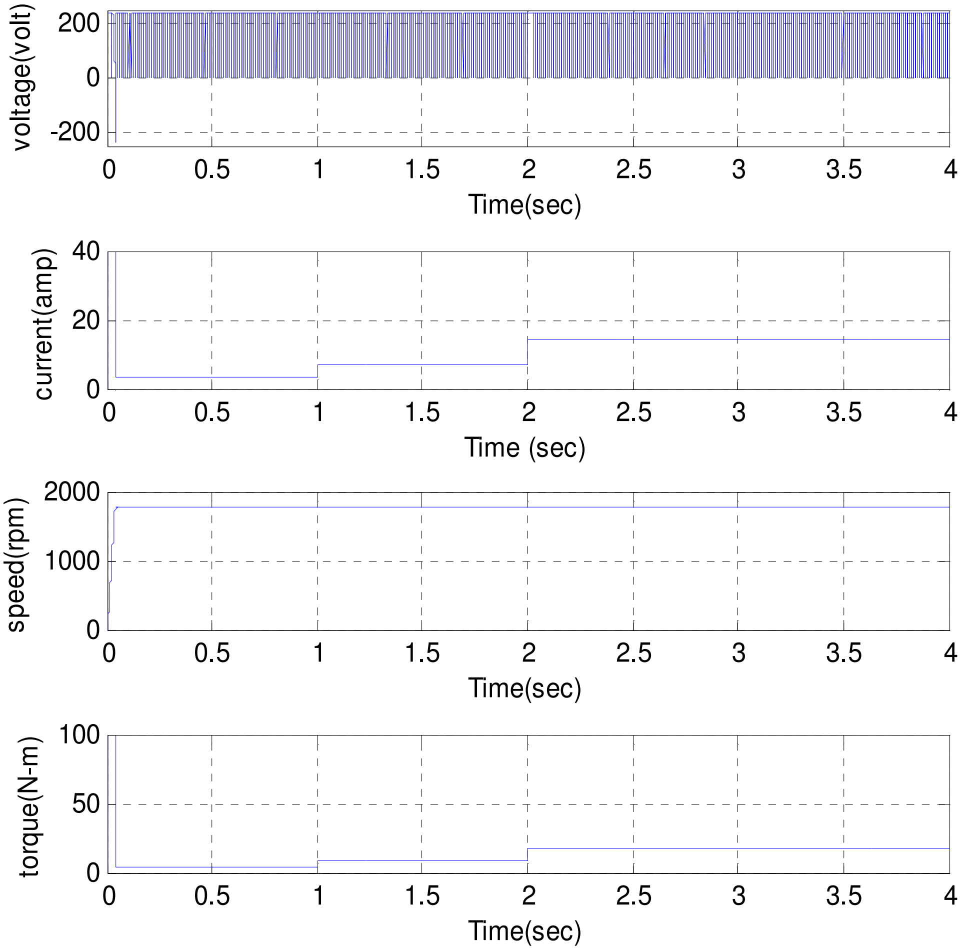

Fig 3.11 Matlab figure diagram for the response of the dc drive with Fuzzy Logic controller on load.

3.4.4 Response of drive with FL Controller on Speed Reversal

Fig 3.12 shows the Matlab figure diagram for the response of the dc drive with FL controller on speed reversal. The figure shows the plot for voltage, current, speed and torque of the motor. At t=1 sec, switching is provided to the motor for speed reversal from 1800 rpm to -1800 rpm and at t= 2 sec, again the switching mechanism is turned ON for speed reversal from -1800 rpm to 1800 rpm. From the figure it is revealed that the motor takes substantial amount of time when switching from one speed to another. This indicates that the FL controller is not able to maintain the speed on switching.

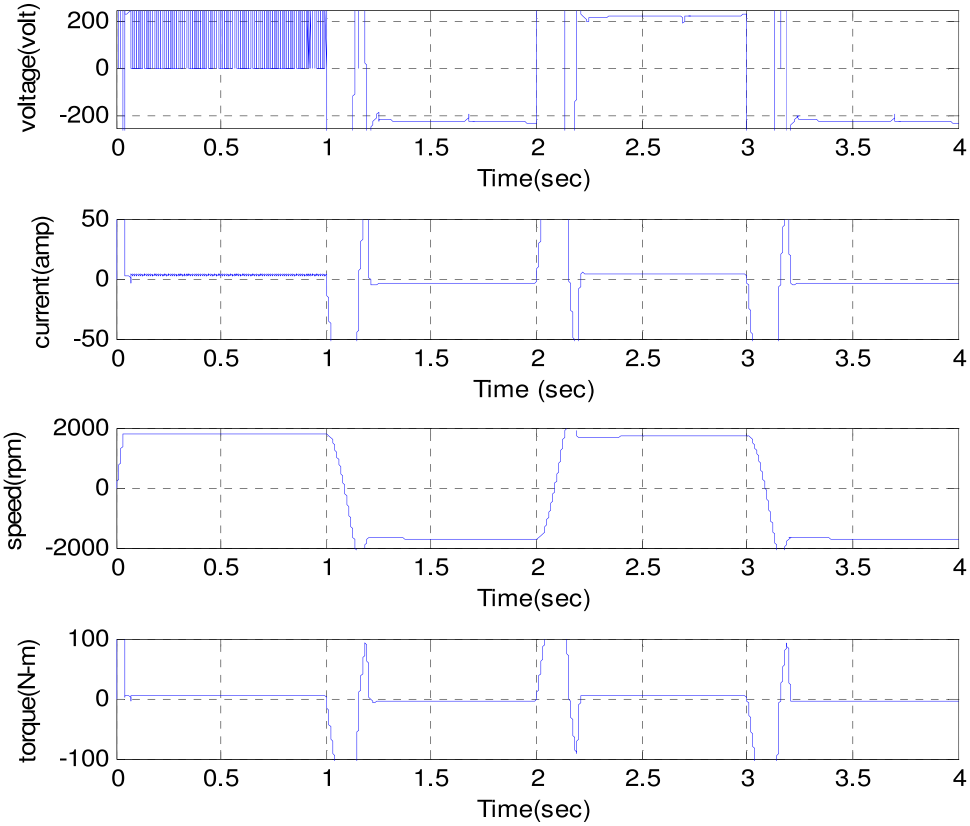

Fig 3.12 Matlab figure diagram for the response of the dc drive with FL controller on speed reversal from 1800 to -1800 rpm.

Similarly, Fig 3.13 shows the Matlab figure diagram when the speed reversal mechanism takes place from 1800 rpm to 1400 rpm. The FL controller is not able to reach 1400 rpm easily. The plot indicates that FL controller alone is not suitable for the application of smooth speed control application.

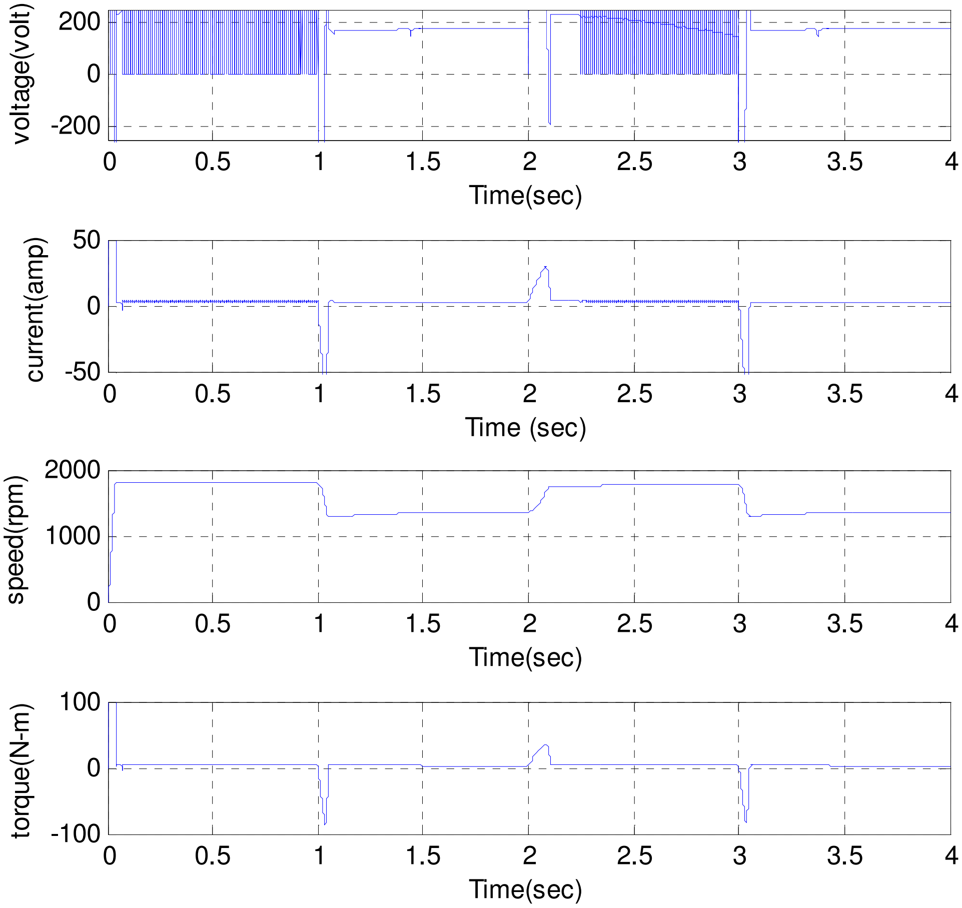

Fig 3.13 Matlab figure diagram for the response of the dc drive with FL controller on speed reversal from 1800 to 1400 rpm

3.4.5 Response of drive with Hybrid Fuzzy Controller on Load

Fig 3.14 shows the Matlab figure diagram for the response of the dc drive with hybrid fuzzy controller. The figure shows the plot for voltage, current, speed and torque of the motor. The settling time at the reference speed 1800 rpm is observed as t= 0.18 sec. At t=1 sec, less than 50% load is applied and at t= 2 sec, around 70% load is applied. A small dip is observed in the speed on load application. From the response it is observed that the hybrid fuzzy controller is more superior than the PI and FL controller.

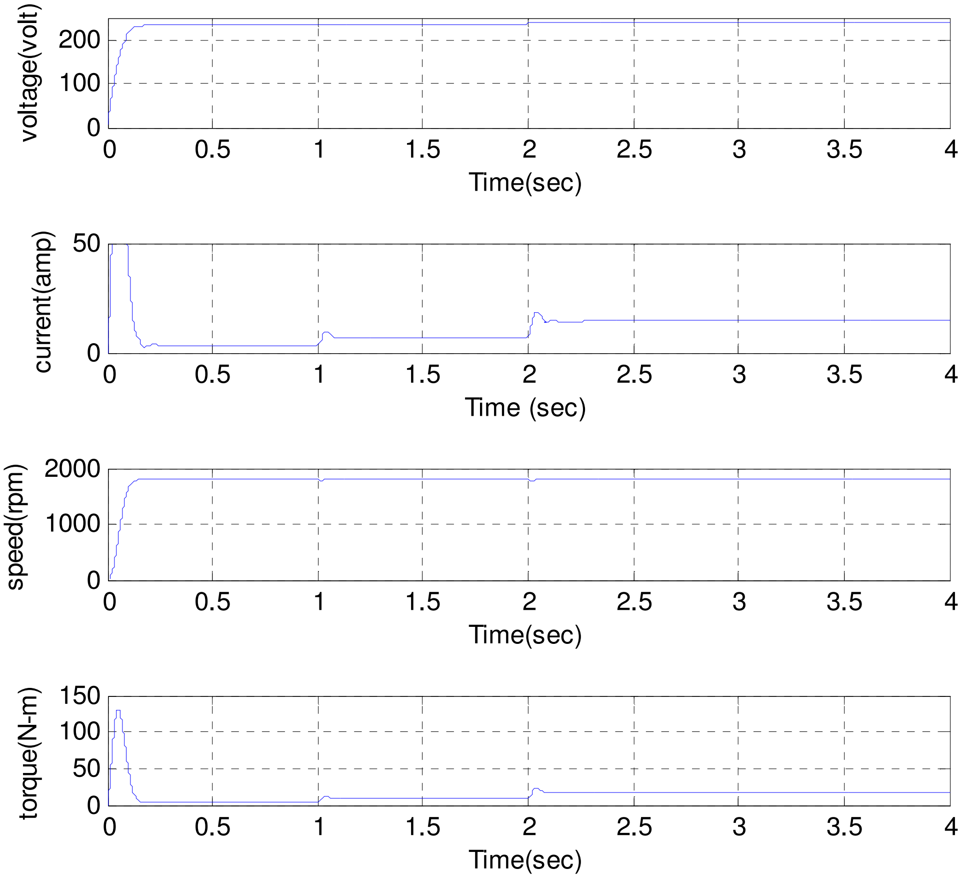

Fig 3.14 Matlab figure diagram for the response of the dc drive with hybrid fuzzy controller on load.

3.4.6 Response of drive with Hybrid Fuzzy Controller on Speed Reversal

Fig 3.15 shows the Matlab figure diagram for the response of the dc drive with hybrid fuzzy controller on speed reversal. The figure shows the plot for voltage, current, speed and torque of the motor. At t=1 sec, switching is provided to the motor for speed reversal from 1800 rpm to -1800 rpm and at t= 2 sec, again the switching mechanism is turned ON for speed reversal from -1800 rpm to 1800 rpm. The figure indicates that the hybrid fuzzy controller has superior performance than the PI and FL controller.

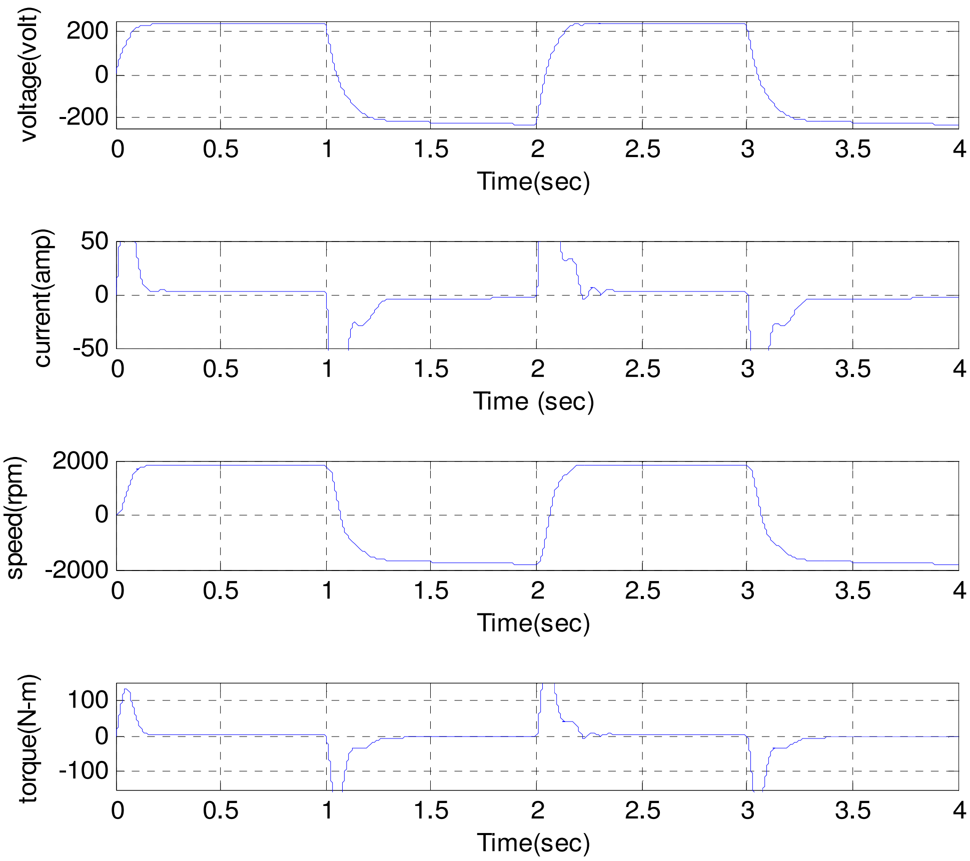

Fig 3.15 Matlab figure diagram for the response of the dc drive with hybrid fuzzy controller on speed reversal from 1800 rpm to -1800 rpm.

Similarly, Fig 3.16 shows the Matlab figure diagram when the speed reversal mechanism takes place from 1800 rpm to 1400 rpm.

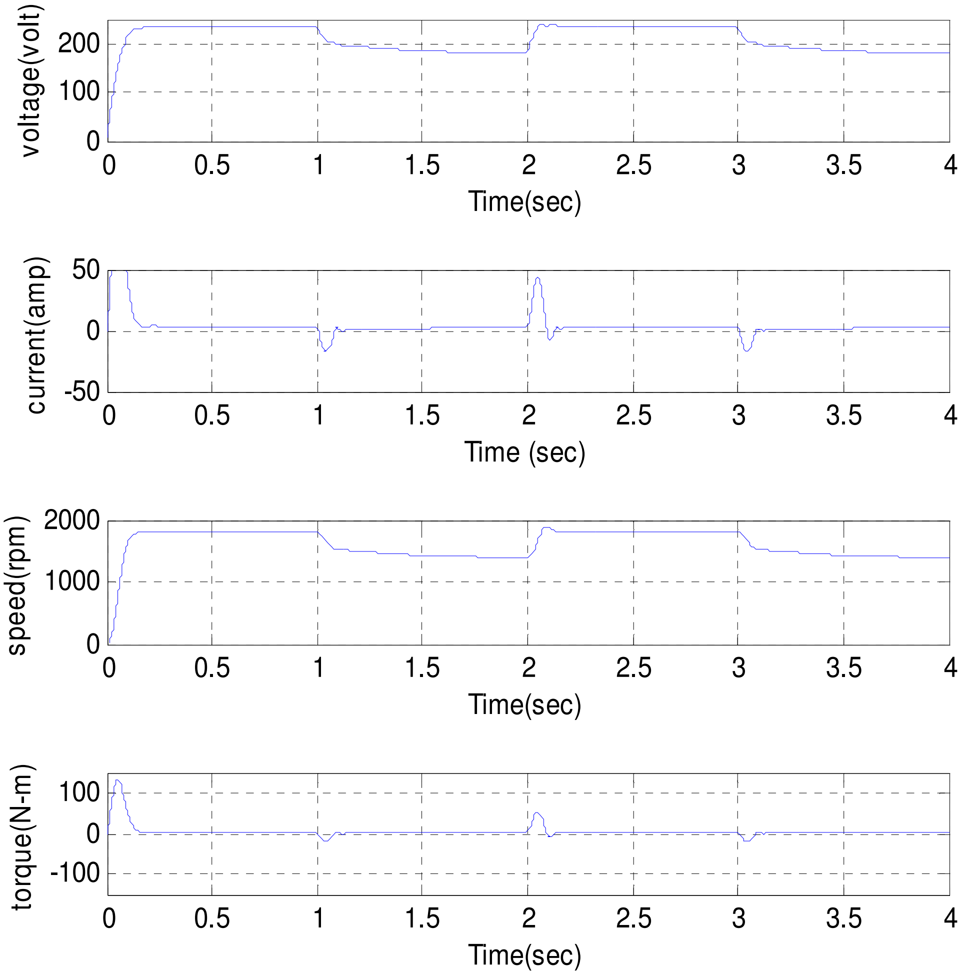

Fig 3.15 Matlab figure diagram for the response of the dc drive with hybrid fuzzy controller on speed reversal from 1800 rpm to 1400 rpm.

3.4.7 Comparative response of drive with PI, FL, and Hybrid Fuzzy controllers under no load.

Fig 3.16 shows the Matlab figure diagram for response (speed) of the dc drive with all the three controllers. The text arrows mark individual curves for the respective controllers.

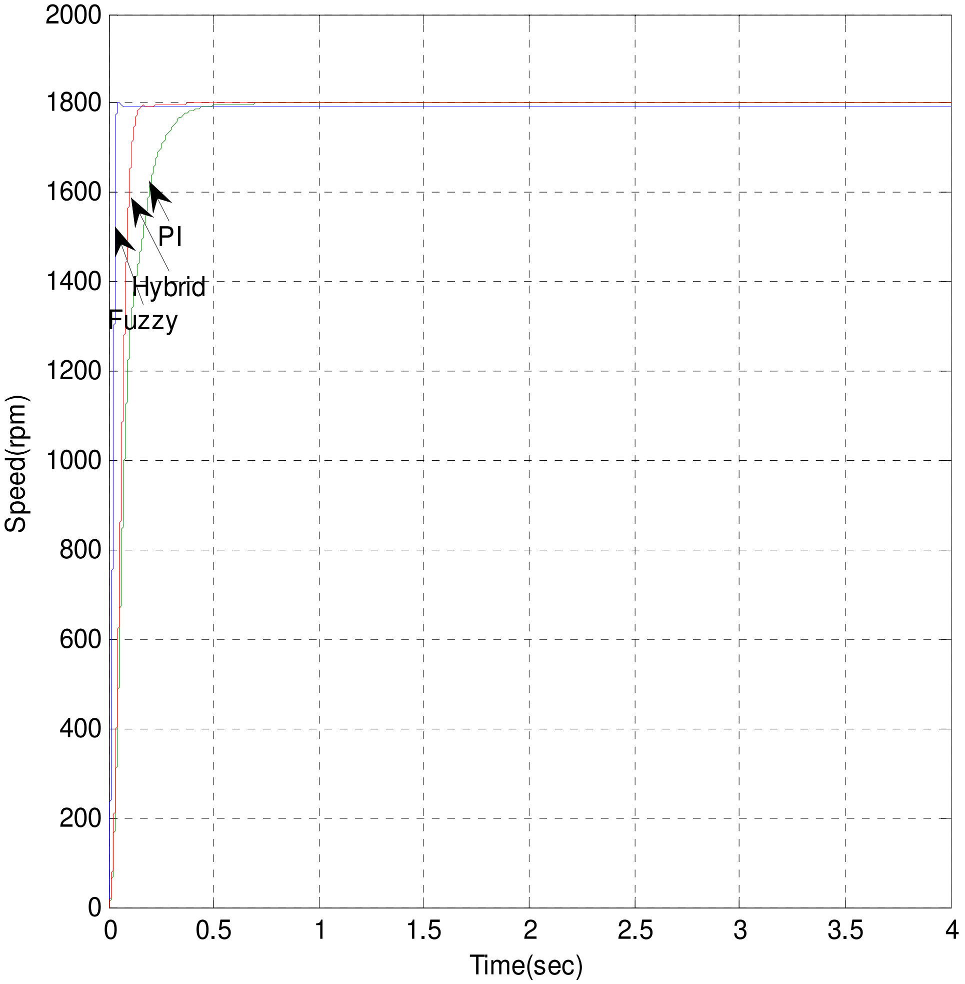

Fig 3.16 Matlab figure diagram for response (speed) of the dc drive with all the three controllers – PI, FL, Hybrid Fuzzy.

3.4.8 Comparative Table of PI, Fuzzy logic, and Hybrid Fuzzy controllers.

S.No.	Controller	Steady State Error	SettlingTime	Overshoot
1.	PI	0	0.6 sec	0
2.	Fuzzy logic	0.1%	0.07 sec	0
3.	Hybrid Fuzzy	0	0.2 sec	0

The comparative table and Fig 3.16 shows the superiority of the hybrid fuzzy controller. The FL controller has a low settling time but the disadvantage of chattering is associated with it. PI controller is fast and robust but it is slow and the tuning of proportional and integral gains is a time consuming process. On the other side, hybrid fuzzy is a combination of PI and fuzzy logic which has the advantages of both of them. Since ,fuzzy is a non linear controller , so in hybrid controller the FL controller is kept out of the drive system. The drive is being controlled by PI controller only but the PI itself is Fuzzy tuned.

3.5 COMPARITIVE STUDY OF VARIOUS CONTROLLERS

3.5.1 PROPORTIONAL INTEGRAL (PI) CONTROLLER

Fig 3.8 , 3.9 and 3.10 shows the different plots for speed control of the dc motor using a Proportional Integral (PI) controller on loading and speed reversal. From the various plots it is seen that by addition of an Integral term with the Proportional gain, the steady state error has been completely eliminated. PI eliminates the error, however increases the settling time. The steady state error is eliminated on the cost of slow response of the drive.

3.5.2 FUZZY LOGIC (FL) CONTROLLER

Fig 3.11,3.12,and 3.13 shows the different plots for speed control of the dc motor using a Fuzzy Logic controller on loading and speed reversal. The conventional speed controllers suffer from the problem of stability, besides, these controllers show either steady date error (PD controller) or sluggish response (PI) to the perturbation in reference setting or during load perturbation. On the other hand the fuzzy logic controller introduces noise at the set point but it has very good transient performance. The main feature of the fuzzy logic controllers is its construction, which utilizes the linguistic imprecise knowledge of human experts. The main advantage of fuzzy logic control method as compared to conventional control techniques resides in fact that no mathematical modeling is required for controller design and also it does not suffer from the stability problem. It bas been recently demonstrated that dynamic performance of electric drives as well as robustness with regards to parameter variations can be improved by adapting the non linear speed control techniques. Fuzzy logic is a non linear control and it allows the design of optimised non linear controllers to improve the dynamic performance of the conventional regulators. However, the FL controller alone is not able to achieve smooth speed control of dc motor, and therefore the need for hybrid controller is obvious.

3.5.3 HYBRID FUZZY SPEED CONTROLLER

Fig 3.14,3.15,3.16 shows the different plots for speed control of dc motor using a Hybrid Fuzzy controller on loading and speed reversal. Hybrid controllers provide a generalization of classical feedback controllers for linear and nonlinear systems. The prime benefits of hybrid controllers is that their performance exceeds any classical linear or nonlinear smooth controller and reflects multiple objectives such as response speed, accuracy, optimality, robustness, and disturbance attenuation. The fuzzy logic controller introduces noises at the set reference speed and shows steady state error. Therefore, there is a need to develop hybrid controllers (combination of fuzzy and PI), which can create or modify rules according to performance measurement based on system parameters. Hybrid Fuzzy speed controller has fuzzy logic controller and PI controller connected in series with each other. A performance comparison between the new controller and the conventional controllers has been carried out by simulation confirming the superiority of the proposed hybrid fuzzy controller.

3.6 CONCLUSION

The separately excited dc motor has been mathematically modeled in MATLAB environment along with simulink toolbox. The drive response has been simulated using the developed model. A comparative study of different speed controllers has been carried out for the drive system. The comprehensive study of different speed controllers for speed control of separately excited dc motor has shown that the individual speed controllers have their own merits and demerits. Depending upon the operation, a choice of a particular speed controller may be made. When the requirement is that of simplicity and ease of application , the PI speed controller is to be a good choice. When intelligence and fast dynamic response are important, then the fuzzy logic technique may be selected. The main demerit in this option is the existence of steady state error. To eliminate such a problem and to maintain high level of performance in combination with fast dynamic response , the hybrid of fuzzy logic and PI is better option. Finally it is concluded that Hybrid controller is a much better choice when the requirement is of high - level accuracy, intelligence and performance. Common industrial practice in many process control applications is to use a conventional proportional plus integral controller to achieve good closed-loop error regulation properties, but to turn off the integral gain when the regulation error is large. For large errors, a purely proportional controller provides fast responses, while for small errors; a proportional plus integral controller provides accuracy and good low-frequency disturbance attenuation. A hybrid controller can be designed to implement switching between a proportional feedback for large errors and a proportional plus integral feedback for small errors. The general approach is that the integrator states are reinitialized to zero whenever the proportional plus integrator feedback is activated.

Chapter IV

CHAPTER IV

MAIN CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

4.1 GENERAL

The main objective of the project has been aimed towards modeling of various controllers for the speed control of a separately excited dc motor. Modeling and simulation of performance of the dc motor has been carried out using different speed controllers in MATLAB environment using Simulink. This chapter is an overall summary of the investigations in the various chapters.

4.2 MAIN CONCLUSIONS

A comprehensive mathematical model of a separately excited DC motor, various controllers- Proportional Integral, Fuzzy Logic Controller, and Hybrid Fuzzy Controller. has been developed in terms of parameters and physical variables (current and voltages) of the motor. The speed response of the DC motor with various controllers has been compared and analyzed. The response of the drive system has been simulated in MATLAB environment using Simulink.

The comparative study of different speed controllers has shown that the individual speed controllers have their own merits and demerits. The choice of a particular speed controller can be made depending upon the type of response they have provided.

Proportional Integral Controller completely eliminates the steady state error, however increases the settling time. The main disadvantage of PI controllers is that the speed of the response becomes slow and the tuning of the parameters is very time consuming. The PI controller is suitable for dc motor speed control but some drawbacks are also associated with this controller. The tuning of the parameters of the PI controllers is very time consuming and the speed of the response also becomes slow. In order to increase the speed of the response of the PI controller, a Saturation block can be used which will be able to pull the motor to the rated current and then the role of the controller can come into action.

Fuzzy Logic Controller’s main advantage as compared to conventional controllers resides in fact that no mathematical modeling is required for controller design. Classic Control has proven for a long time to be good enough to handle control tasks on system control, however its implementation relies on an exact mathematical model of the plan to be controller and not simple mathematical operations. The fuzzy logic, unlike conventional logic system, is able to model inaccurate or imprecise models. The fuzzy logic approach offers a simpler, quicker and more reliable solution that is clear advantages over conventional techniques. Fuzzy logic controllers have been suggested as a promising alternative approach for controlling processes, especially those that are too complex for conventional techniques. The rationale behind Fuzzy logic controllers is that an experienced human operator can completely control the process without the knowledge of its underlying dynamics. The effective control strategies that a human operator learns through his or her experience can be expressed as a set of condition- action rules (called fuzzy rules), which describe conditions about the process state using linguistic terms.

The dynamic model and MATLAB SIMUATION of the Hybrid Fuzzy controller for a separately excited dc motor has been carried out. While PI controllers are widely used in industrial applications, they exhibit poor performance when applied to systems containing unknown nonlinearities, such as dead zones, saturation, and hysteresis. Fuzzy logic based pre compensation scheme for PI controllers have yielded superior results than conventional controllers. The purpose of the Hybrid Fuzzy controller is to modify the command signal to compensate for the overshoot and undershoots present in the output response when the plant has unknown nonlinearities. A performance comparison between the new controller with conventional controllers and fuzzy controller has been carried out by simulation confirming the superiority of the proposed. The advantage of this approach is that an existing PI control system can be easily modified into the hybrid fuzzy structure by adding the fuzzy pre compensator.

4.3 SUGGESTIONS FOR FURTHER WORK

Although the objectives set forth at the outset of the project have been successfully achieved, certain aspects require further investigation. Several self-tuning control (STC) algorithms have been developed theoretically, and many simulation results have demonstrated their feasibility during recent times. Such hybrid adaptive controller can achieve better response with less computation time. In another way with the advent of advanced microprocessors the implementation of self-tuning algorithms has become relatively easy .There is a need to implement these advanced controllers on such advanced microprocessors.

The Hybrid fuzzy controller uses a fuzzy pre compensator, whose purpose is to modify the command signal to compensate for the overshoots and undershoots present in the output response when the plant has unknown nonlinearities. We can also develop a different type of hybrid fuzzy controller - Parallel type hybrid controller in which the FL controller and the PI controller are connected in parallel with each other and FL controller continuously updates both the proportional and integral gains of the PI controller till the most optimum values for both the gains is achieved , thus making the proposed controller more dynamic and robust in nature. Such a controller is expected to have a more crisp and better performance and is a topic for future work. Hybrid Fuzzy controller with self organizing structure of fuzzy pre compensator may also be studied for most robust and high performance range of controllers.

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ANNEXURE

1. Values of gains of PI controller used.

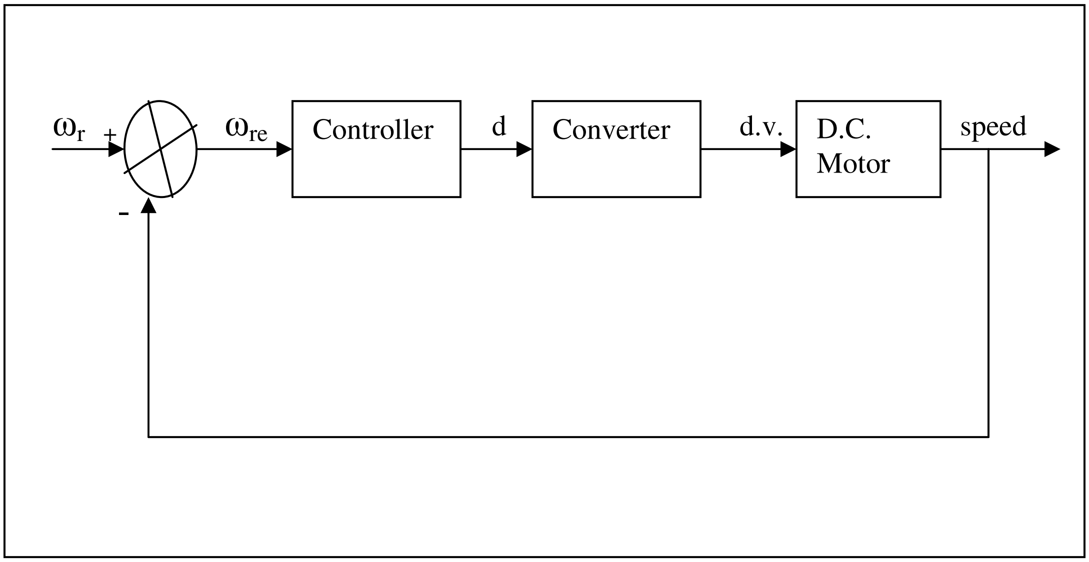
Proportional gain constant K_p = 0.0004

Integral gain constant K_I = 0.225

2. Data of Motor.

Separately excited DC motor – 2 pole, 240V, 5 hp.

3. Block diagram of physical system.



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