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Performance Comparison of Speed Control of Chopper fed DC Motor for Various Controllers

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ABSTRACT: This paper presents a comparative study of speed control of a separately excited DC motor by using different type of controllers. .Conventional controllers are commonly being used to control the speed of the DC motors in various industrial applications. It's found to be simple, robust and highly effective when the load disturbance is small. But during high load or rapid variation of load, the fuzzy technique based controllers proves to be fast and reliable. Using chopper input voltage can be varied and thus speed can be varied. For better performance of the DC motor various kind of controller namely P-I, I-P, Fuzzy logic controller are used. Proportional-Integral type controller is used to eliminate the delay and provides fast control. However, the P-I controller has some disadvantages such as: sluggish response to a sudden load change, the high starting overshoots and sensitivity to controller gains. So, the relatively new Integral Proportional (I-P) controller is proposed to overcome the disadvantages of the P-I controller .After obtaining the model of separately excited DC motor, it is simulated using MATLAB (Simulink) environment. Then fuzzy logic controller has been designed and performance has been observed. Finally a comparative study is done between all the controllers.

KEYWORDS: Chopper, P-I Controller, I-P Controller, Fuzzy Logic Controller, Speed Control, DC Motor

1 INTRODUCTION

High performance motor drives are very much essential for industrial application. Most of the industries demand variable speed operation of motor. As synchronous motor is a constant speed motor so it is used in industries which demands constant speed operation of motor. Speed of DC motor can be varied below and above the rated speed by terminal voltage control and field flux control respectively. So DC motor is used in many applications such as steel rolling mills, electric vehicles, electric trains, electric cranes and robotic manipulators require speed controller to perform its tasks smoothly. DC motors provide good control of speed for acceleration and deceleration. Speed controller of dc motors is carried out by means of voltage control in 1981 by Ward Leonard for the first time.

Because of their simplicity, reliability, and low cost DC drives have long been used in industrial applications. Compared to AC drives system DC drives are less complex .For low horsepower ratings DC drives are normally less expensive. DC motors have been used as adjustable speed machines since long and a wide range of options have evolved for this purpose. DC motors are capable of providing starting and accelerating torque 4 times the rated torque. DC motors have long been the primary means of electric traction. They are also being used for mobile equipment like quarry, golf carts, and mining applications. DC motors are portable and well fit to special applications, like industrial equipment and machineries that are not easily run from remote power sources.

DC motor is a SISO (Single Input and Single Output) system which has torque/speed characteristics compatible with most mechanical loads. This makes a DC motor controllable over a wide range of speeds by proper adjustment of the terminal voltage. The regulated voltage sources used for DC motor speed control have gained more importance after the introduction of thyristors as switching devices in power electronics .Then semiconductor components such as MOSFET, GTO and IGBT have been used as electric switching devices. As the theory of DC motor speed control is extendable to other types of motors as well, hence DC motors are always a good option for advanced control algorithm.

2 CHOPPER

2.1 PRINCIPLE OF OPERATION

A chopper is a high speed on-off switch which converts fixed DC input voltage to a variable DC output voltage. A Chopper is considered as a DC equivalent of an AC transformer as they behave in an identical manner. Choppers are more efficient as they involve one stage conversion.

Choppers are now being used all over world for rapid transit systems. These are also used in marine hoist, trolley cars, mine haulers and forklift trucks. It is predicted that in future electric automobiles will be using choppers for their speed control and braking purpose. Chopper offer high efficiency smooth control, regeneration facility and faster response. The power semiconductor devices used for a chopper circuit can be force commutated thyristor, power BJT, IGBT, GTO and MOSFET based chopper are also used. These devices are represented by a switch. When the switch is being “off”, current does not flow. Current flows through the load when switch is “on”. When we switch it “on” it connect the load with source and when we put it at “off” it disconnect the load from source at a very fast speed .The on-state voltage drop of power semiconductor devices is nearly 0.5V to 2.5V across them. But for the sake of simplicity, the voltage drop across these devices is considered to be zero but practically it is not zero.

As mentioned above, a chopper is considered to be DC equivalent of AC transfer. Voltage can be step up or step down by varying the duty ratio of chopper as it is done by varying the turns ration in a transformer. from the figure we can see that during the period Ton, chopper is on and hence load voltage is equal to source voltage Vs and during the period Toff, chopper is off and hence load voltage is zero. In this way, a chopped dc voltage is produced at the load terminal.

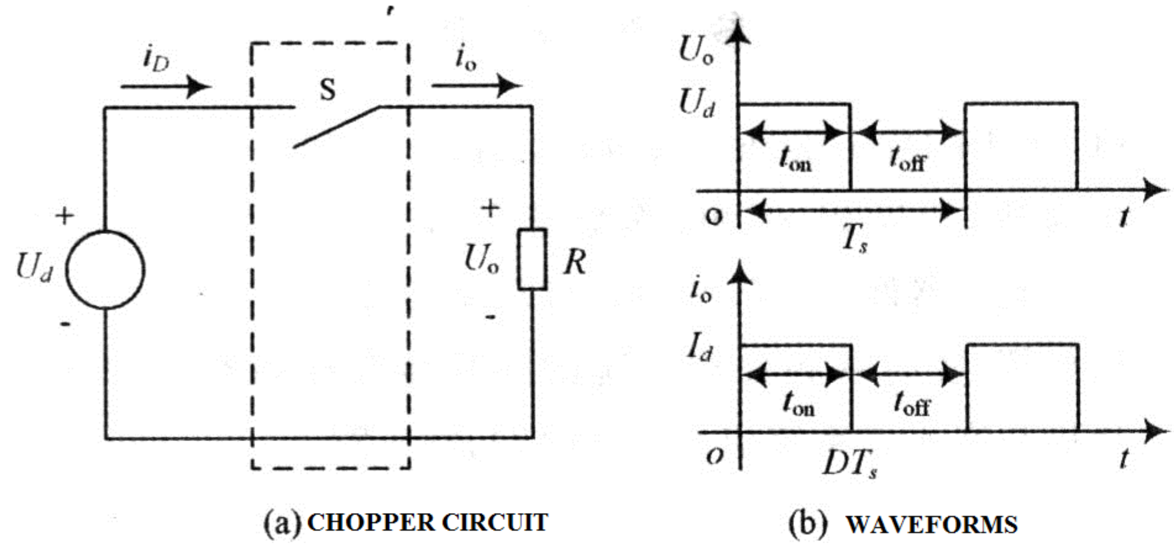

Figure 1. Chopper Circuit and its waveform

2.2 CONTROL METHODS

The average value of output voltage Vo can be controlled through changing duty cycle by opening and closing the semiconductor switch periodically. Followings are the different control strategies for varying duty cycle:

- Time Ratio Control
- Current Limit Control

2.2.1 TIME RATIO CONTROL

In this control scheme, time ratio is varied. This is done in two ways:

- Constant Frequency System

In this scheme, on-time is varied but chopping frequency f is kept constant. This is also called Pulse-width modulation scheme.

- Variable Frequency System

In this scheme, the chopping frequency f is varied and the on-time or off-time remains constant. So, duty ratio is varied either by keeping Ton constant or Toff constant.

2.2.2 CURRENT LIMIT CONTROL

In this control method, turning on and off of chopper circuit is decided by the previous set value of load current. The set values are upper limit of load current and lower limit of load current that is maximum and minimum load current. When the load current reaches the upper limit, chopper is being switched off. When the load current falls below lower limit, the chopper is being switched on. Switching frequency of chopper can be controlled by varying the maximum and minimum level of load current.

3 MODELLING OF SEPARATELY EXCITED DC MOTOR

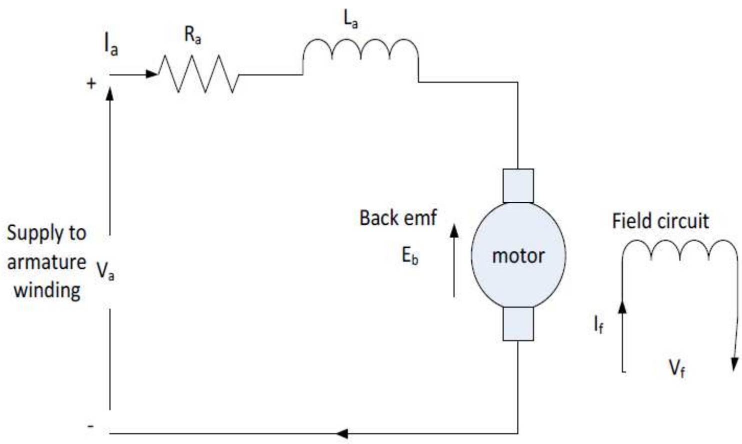

Figure 2. Separately Excited DC Motor Model

The armature equation is shown below:

$$V_a = E_b + I_a R_a + L_a \left(\frac{dI_a}{dt}\right)$$

Where

V_a is armature voltage in volts.
E_b is motor back emf in volts
I_a is armature current in amps
R_a is armature resistance in ohms
T_L is load torque in Nm
T_d is torque developed in Nm
J is moment of inertia in kg/m2
B is friction coefficient of the motor
w is angular velocity in rad/sec

Taking Back EMF Constant as K_b and Electrical toque constant as $K_{T,}$ Equation for back emf of motor can be written as :

$$E_b = K_b w$$

$$T_d = K_T I_a$$

From Motor's Basic Armature equation and taking Laplace Transform on both sides of equation: We get,

$$I_a(s) = (V_a - E_b)/(R_a + L_a s)$$

From Torque equation, we have

$$w(s) = (T_d - T_L)/(Js + B)$$

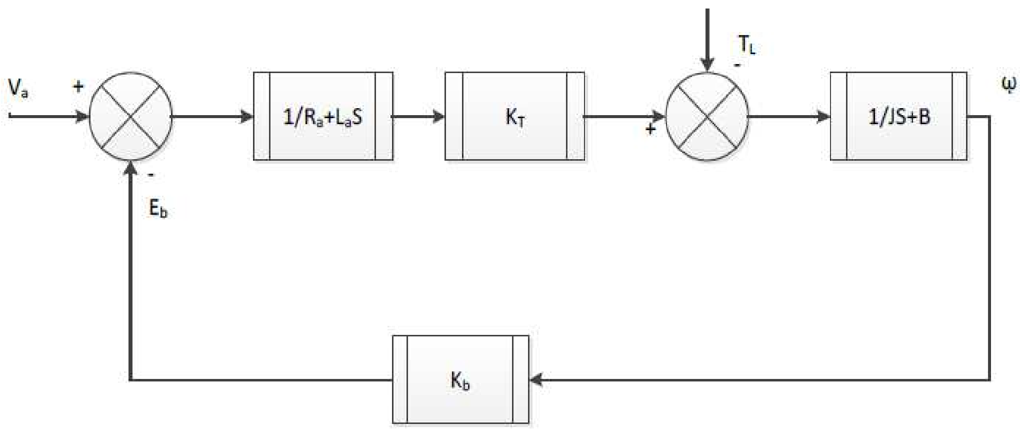

Figure 3. Block Model of Separately Excited DC Motor

4 P-I AND I-P CONTROLLERS

A comparative study of PI & IP control scheme for a dc drive has been done here. The response of both P-I and I-P the controller for a change in speed reference and load torque is discussed. A one quadrant GTO chopper is used as power conditioning unit in the experimental set up using a separately excited dc motor. Most DC motor drives are operated as closed-loop speed control system.

A simple proportional gain in the speed loop may not be sufficient to provide a precise control on the speed of drives. This may results in a high overshoot and also an undesirable steady state error in speed. Therefore some kind of compensation technique has to be employed to improve the performance of the drive. The mostly used compensation method for DC motor drive is the proportional plus integral (P-I) control.

4.1 PROPORTIONAL-INTEGRAL (P-I) CONTROLLER

The block diagram of the motor drive with the P-I controller has one outer speed loop and one inner current loop, as shown in Fig. 1. The speed error EN between the reference speed NR and the actual speed N of the motor is fed to the P-I controller, and the Kp and Ki are the proportional and integral gains of the P-I controller. The output of the P-I controller E1 acts as a current reference command to the motor, C1 is a simple proportional gain in the current loop and KCH is the gain of the GTO thyristor chopper. For analysis the electrical time constant can be neglected, since it is very small as compared to mechanical time constant of the motor.

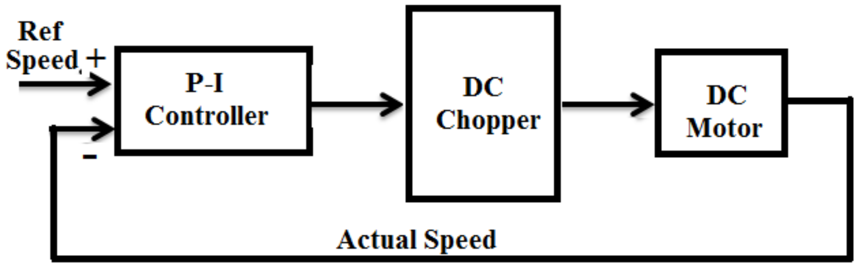

Figure 4. P-I Controller based Speed Control of Chopper fed DC Motor

4.2 INTEGRAL -PROPORTIONAL (I-P) CONTROLLER

The block diagram of motor drive with the I-P controller has the proportional term KP moved to the speed feedback path. There are three loops one speed feedback loop, one inner current loop, and one feedback loop through the proportional gain KP. The speed error EN is fed to a integrator with gain KI and the speed is feedback through a proportional gain KP.

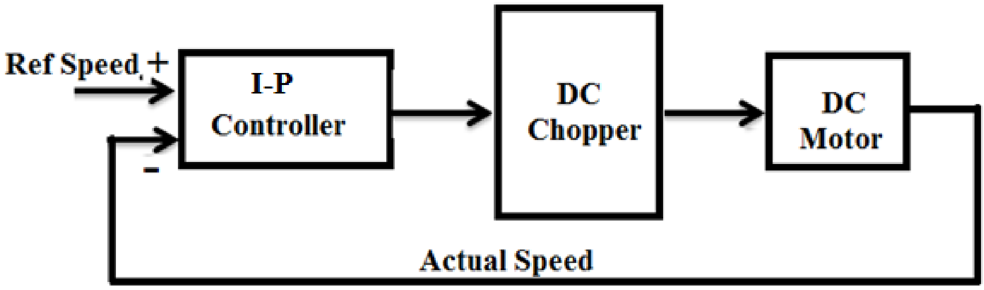

Figure 5. I-P Controller based Speed Control of Chopper fed DC Motor Comparative Analysis of Speed Response of Chopper Fed DC Motor using P-I and I-P Controller

The MATLAB/SIMULINK Model for Speed Control of Chopper fed DC Motor using P-I Controller is shown below:

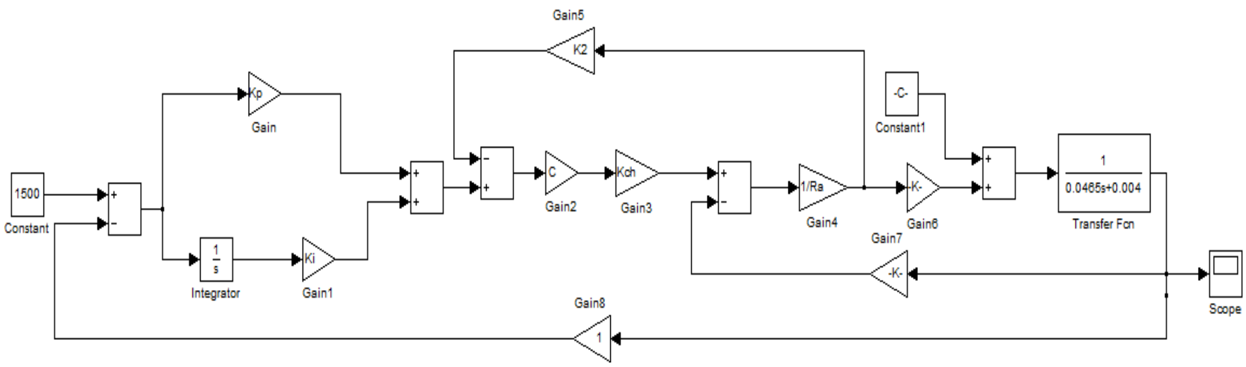

Figure 6. Simulink Model of P-I Control for Chopper fed DC Motor

The MATLAB/SIMULINK Model for Speed Control of Chopper fed DC Motor using I-P Controller is shown below:

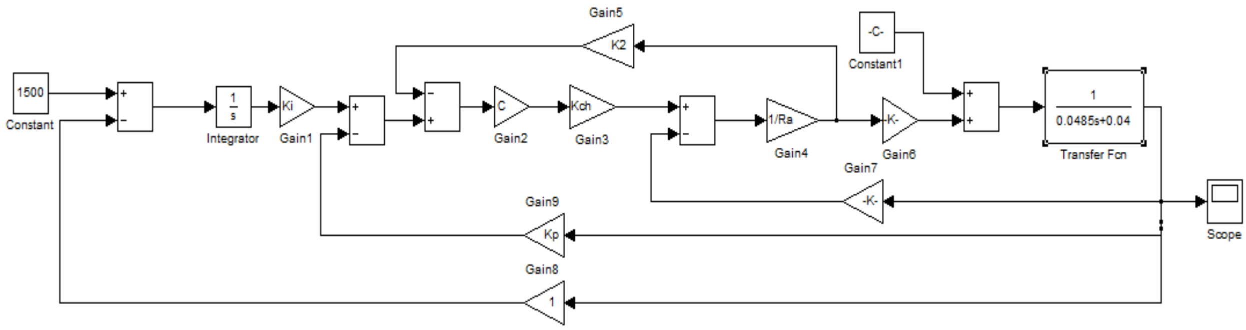

Figure 7. Simulink Model of I-P Control for Chopper fed DC Motor

In case of the P-I controller an overshoot in speed can be seen, but the I-P scheme shows Negligible overshoot. It is clear from Figs.12 that the I-P controller performs slightly better than the P-I controller. The following table shows a comparison between PI and IP controller.

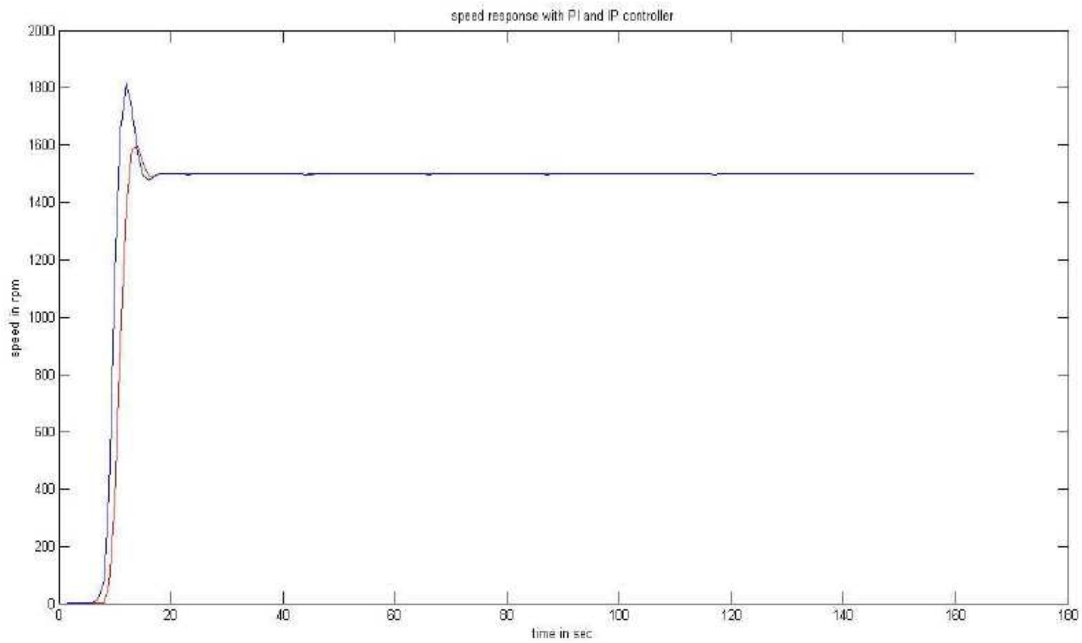

Figure 8. Comparison of Speed Response of Chopper fed DC Motor using P-I and I-P Controllers

	P-I Controller	I-P Controller
% Mp	20%	7.67%
Rise Time	10.4 sec	12 sec
Settling Time	18 sec	19 sec

5 FUZZY LOGIC CONTROLLER

Fuzzy logic control is one of the control algorithm based on a linguistic control strategy, which is being derived from expert knowledge into an automatic control strategy. Fuzzy logic control doesn't need any kind of difficult mathematical calculation like the others control system. While the others type of control system use difficult mathematical calculation to provide a model of the controlled plant, fuzzy uses only simple mathematical calculation to simulate the expert knowledge. Although it doesn't need any difficult mathematical calculation, but it give good performance in a control system. Thus, it can be one of the best available answers today for a broad class of challenging controls problems.

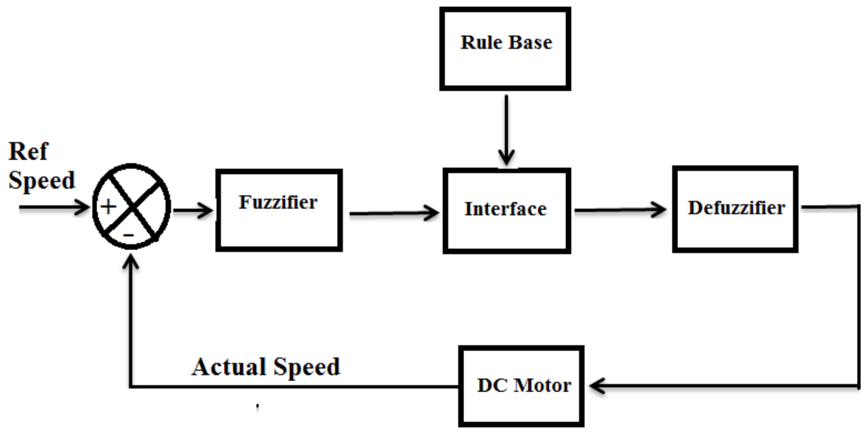

Figure 9. Block Diagram of Fuzzy Logic Controller

5.1 FUZZIFICATION MODULE

This process converts the measured inputs called crisp input, into the fuzzy linguistic values. The first step in designing a fuzzy controller is to decide which state variables represent the system dynamic performance must be taken as the input signal to the controller. Generally Fuzzy logic uses linguistic variables instead of any precise or numerical variables. The process of transforming a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called Fuzzification. System variables, which are generally used as the fuzzy controller inputs includes states error, state error integral, state error derivative or etc. Here speed error and its derivative i.e change in speed error are chosen as the input signals.

5.2 RULE BASE

A collection of the expert control rules (knowledge) needed to achieve the control goal. This process will perform fuzzy logic operations and result the control action according to the fuzzy inputs.

5.3 DEFUZZIFICATION MODULE

The reverse of Fuzzification is called Defuzzification. It is the transformation of a fuzzy quantity into a precise quantity, just like fuzzification is the conversion of a precise quantity to a fuzzy quantity. The use of Fuzzy Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number).As per the real world requirements, the linguistic variables should to be transformed to a crisp output.

5.4 MEMBERSHIP FUNCTION

The most important things in fuzzy logic control system designs are the process design of membership functions for inputs and outputs and design of fuzzy if-then rule knowledge base. A membership function is a graphical representation of the magnitude of participation of each input. There can be different memberships functions associated with each input and output response. In this study, we used the triangular membership function for input and output variables. The quality of control which can be achieved using fuzzy controller is determined by the number of membership function .With increase in the number of membership function, the quality of control improves. When the number of linguistic variables increases, the computational time and required memory also increases. Therefore, a compromise has to be considered between the quality of control and computational time to choose the number of linguistic variables. For the speed control of DC motor study, seven linguistic variables for each of the input and output variables are used to describe them.

5.5 Fuzzy Rule Base For Speed Control of DC Motor

e / ce	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Figure 10. Fuzzy Rules Table

6 Simulink Model of Speed Response of Chopper Fed DC Motor Using Fuzzy Controller

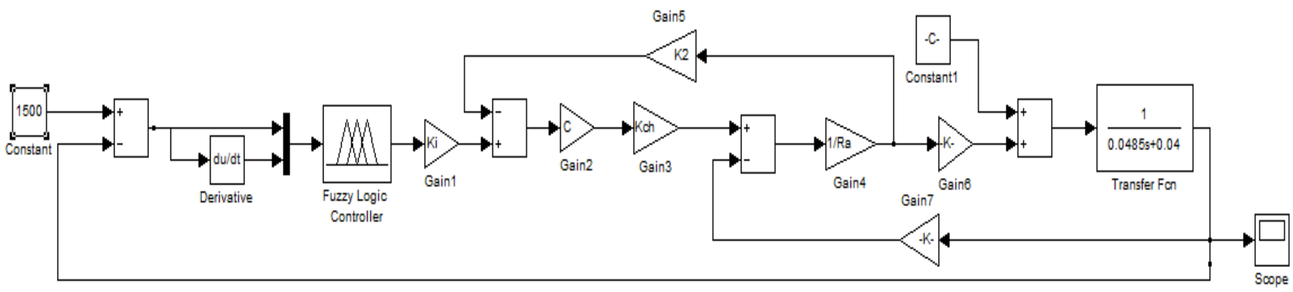

Figure 11. Simulink Model of FLC Control for Chopper fed DC Motor

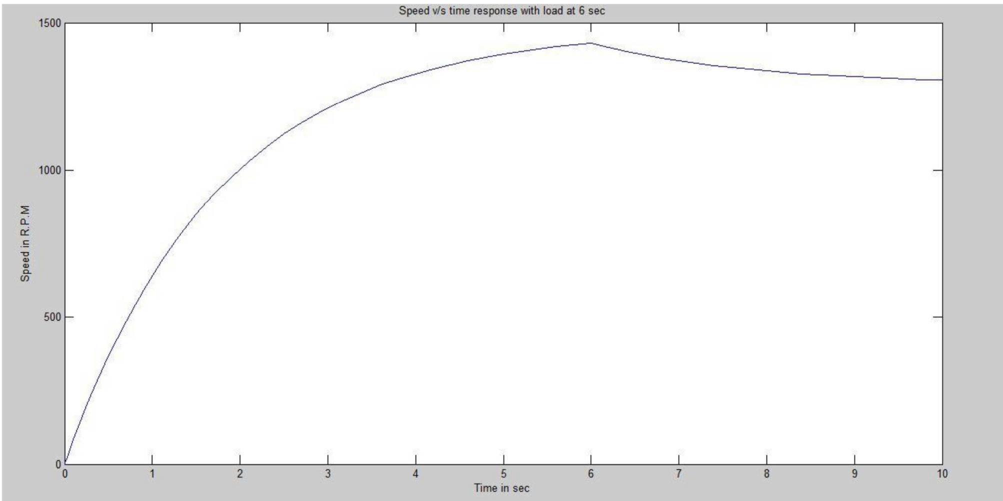

Figure 12. Speed Response of Chopper fed DC Motor using Fuzzy Logic Controller

	P-I Controller	I-P Controller	Fuzzy Logic Controller
% Mp	20%	7.67%	0%
Rise Time	10.4 sec	12 sec	3.9 sec
Settling Time	18 sec	19 sec	4.5 sec

The performance of fuzzy controllers is compared by setting the reference speed to 1500 rpm from the initial condition. The results are shown in Figs. The performance of fuzzy controller is also tested by applying a large step change in load at time 6 sec. The system response for the above case is shown in Figs. In fuzzy control system we have smooth control with less overshoot and no oscillations than P-I and I-P controllers. It is observed that I-P controller provides more advantages over the traditional P-I controller such as limiting the overshoot in speed, thus the overshoot in starting current can be reduced.

7 CONCLUSION

A comparison has been done between the performance of P-I and I-P controller for dc motor control by setting the reference speed to 1500 rpm. The response is shown in Figs.12. It is clear from Figs.12 that the I-P controller performs slightly better than the P-I controller. The speed of a separately excited DC Motor has been successfully controlled by using fuzzy logic controller technique. The performance of fuzzy controller is compared by setting the reference speed to 1500 rpm from the initial condition. It has been found that fuzzy logic controller performs in a better way than the other conventional controllers with less overshoot and no oscillations. Graph for the speed response of separately excited DC Motor using fuzzy logic controller is compare with graph for the speed response of separately excited DC Motor without fuzzy logic controller.

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