Comparative analysis of Speed Control of DC Motor using PI & Fuzzy Logic Controller

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Abstract— The development of technologies affects the demands of industries at the present time. Thus, automatic control has played a vital role in the advancement of engineering and science. In today's industries, control of DC motors is a common practice. Therefore, implementation of DC motor controller is required. There are many types of controller that can be used to implement the elegant and effective output. PI controller and fuzzy logic controllers are widely used such type of controllers. Fuzzy logic and PI controllers are designed to eliminate the need for continuous operator attention thus provides automatic control to the system. Cruise control in a car and a house thermostat are common examples of how controllers are used to automatically adjustsome variable to hold the measurement (or process variable) at the set-point. The purpose of both these techniques is to achieve accurate trajectory control of speed.This project focuses on comparison between PI controller and Fuzzy logic controller for controlling the speed of a dc motor.

Key words: DC motor, PI controller, Fuzzy logic controller, Three phase fully controlled rectifier, etc.

I. INTRODUCTION

The DC motors are used in various applications such as defence, industries, Robotics etc. DC drives because of their simplicity, ease of application, reliability and favourable cost have long been a backbone of industrial application. DC drives are less complex with a single power conversion from AC to DC. DC drives are normally less expensive for most horse power ratings. DC motors have long tradition of use as adjustable speed machine and wide range of options have evolve for this purpose.

Almost every industry and householdhas used motor in their equipment or appliances. The motors that are often used by the computers have also become an essential part of many motion control systems. Many advanced method have been develop to obtain the response of the system close to the desired response. Some of these methods are based on PI controller and fuzzy logic which was developed by Zadeh. In this paper speed of DC motor has been controlled with the help of PI controller and fuzzy logic controller and comparison between both controllers response has been analysed. In close loop speed control DC motor, controllers decide the firing angle of the three phase fully controlled rectifier which in turn controls the speed of DC motor.

The basic block diagram of the system is as shown below.

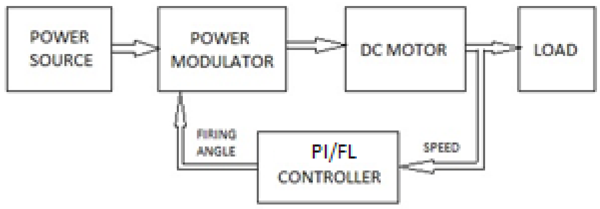

Fig. 1: basic block diagram of dc motor drive

II. PI CONTROLLER

Proportional + integral (PI) controllers were developed because of the desirable property that system with open loop transfer function of type 1 or above have zero steady state error with respect to step input.

In time domain-

$Y(t) = K_p e(t) + K_i \int e(t)dt$

Taking Laplace transform of above function

$Y(s) = K_p E(s) + K_i E(s)/S$

The block diagram of PI controller is as shown below

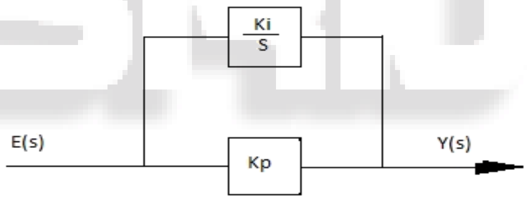

Fig. 2: basic block diagram of PI controller

The transfer function of the PI controller looks like the following:

$$\frac{Y(s)}{E(s)} = Kp + Ki/S$$

K_p = Proportional gain

K_I = Integral gain

The variable (e) represents the tracking error, the difference between the desired input value (R) and the actual output (Y). This error signal (e) will be sent to the PI controller, and the controller computes the integral of this error signal. The signal (u) just past the controller is now equal to the proportional gain (Kp) times the magnitude of the error plus the integral gain (Ki) times error.

$$U = K_p e + K_i \int e(t)dt$$

This signal (u) will be sent to the plant, and the new output (Y) will be obtained. This new output (Y) will be sent back to the sensor again to find the new error signal (e). The controller takes this new error signal and computes its derivative and it's integral again. This process goes on and on.

A. The Characteristics of P And I Controllers

A proportional controller (K_p) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse. Effects of each of controllers K_p and K_i on a closed-loop system are summarized in the table shown below.

Controller response	Rise time	Overshoot	Settling time	s-s error
K_p	Decreases	Increases	Small change	Decrease
K_i	Decrease	Increases	Increases	Eliminate

Note that these correlations may not be exactly accurate, because K_p and K_i are dependent of each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for K_p and K_i.

B. Tuning Rules of Pi Controller

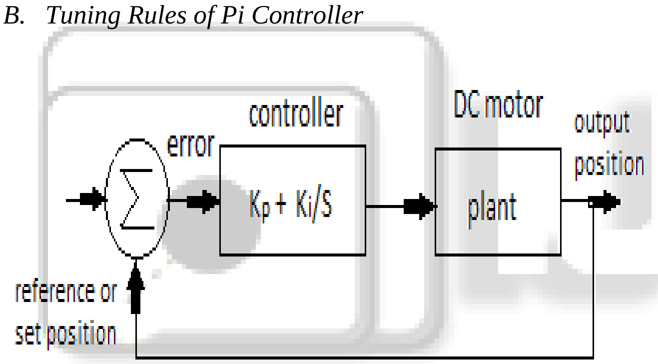

Fig. 3: Position Control System

Figure 3 shows the position of PI controller in dc motor speed control system. If the mathematical model of the plant (dc motor) can be derived, then it is possible to apply various design techniques for determine parameters of the controller that will meet the transient and steady-state specification of the close loop system.

The process of selecting controller parameter to meet given performance specification is known as controller tuning. Ziegler and Nichols suggested rules for tuning PI controller (mean to set the values of Kp and Ki) based on the experimental step response or based on the value of Kp that result is marginal stability when only proportional control action is used [5]. Ziegler-Nichols rules, which are briefly presented in the following, are useful when mathematical models of plans are not known. These rules can, of course, be applied to design of system with known mathematical models. Such rules suggest a set of values of Kp and Ki that will give a stabile operation of the system. However, the resulting system may exhibit a large maximum overshoot in step response, which is unacceptable. In such a case, we need series of fine tunings until an acceptable result is obtained. In fact, the Ziegler-Nichols tuning rules give an educated guess for parameter values and provide a starting point for fine tuning, rather then giving the final settings for Kp and Ki in a single shot.

Ziegler and Nichols proposed rules for determining values of proportional gain, Kp and integral time, Ki based on the transient response characteristics of given plant. Such determination of the parameter of PI controller or tuning of PI controller can be made by engineers on-site by experiments on the plants. Numerous tuning rules for PI controllers have been proposed since the Ziegler-Nichols proposal. They are available in the literature and from the manufactures of such controllers. There are two methods called Ziegler-Nichols tuning rules; the first method and the second method.

C. First Method

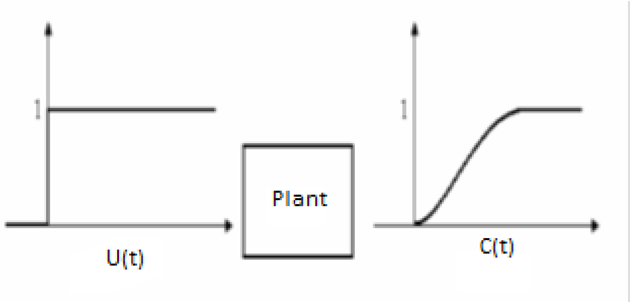

Fig. 4: Response to a unit-step input

In the first method, we obtain experimentally the response of the plant to a unit-step input, as shown in figure 2.3. If the plant involves neither integrator(s) nor dominant complex-conjugate poles, then such a unit-step response curve may look S shape as shown in figure. This method applies if a response to a step input exhibit an S-shaped curve. Such step-response curves may be generated experimentally of from dynamic simulation of the plant.

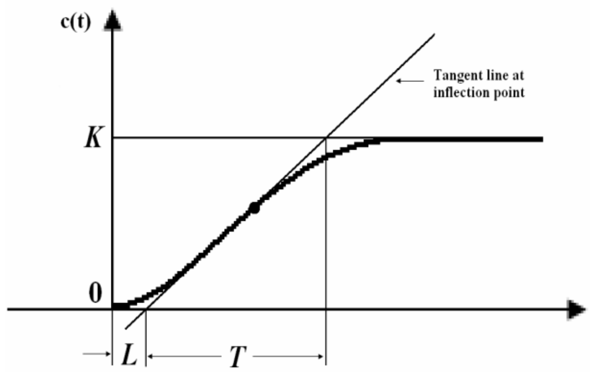

Fig. 5: Response with tangent line

The S-shape curve may be characterized by two constants, delay time L and time constant T. The delay time and constant time are determined by drawing a tangent line (Figure 2.4) at the inflection point of the S-shaped curve and determining the intersections of the tangent line with the time axis and line c(t) = K as shown in figure. The transfer function C(s) /U(s) may then be approximated by fist-order system with transport lag as follows;

$$\frac{C(s)}{U(s)} = \frac{Ke^{-Ls}}{Ts+1}$$

Ziegler and Nichols suggested setting the value of K_p and K_i according to the formula shown in Table.

Type of controller	K_P	K_I
P	T/L	∞
I	0.9T/L	L/0.3

Notice that the PI controller tune by the first method of Ziegler-Nichols rules gives

$$G(s) = Kp\left(1 + \frac{1}{KiS}\right)$$

$$= 0.9\frac{T}{L}\left(1 + \frac{1}{L/0.3}\right)$$

$$= 0.9\frac{T}{L}\left(1 + \frac{0.3}{L}\right)$$

The first method explains about how to tune the PI controller in the first order system only. But this project is about second order close loop system. A study need to be done to tune the second order system in the second method.

D. Second Method

In the second method, Ki = ∞ was set. Using the proportional control action only (see figure), increase Kp from 0 to a critical value K_{cr} at which the output first exhibits sustained oscillations. (If the output does not exhibit sustained oscillations for whatever value of K_p may take, then this method does not apply) Thus, the critical gain K_{cr} and the corresponding period P_{cr} are experimentally determined (see figure).

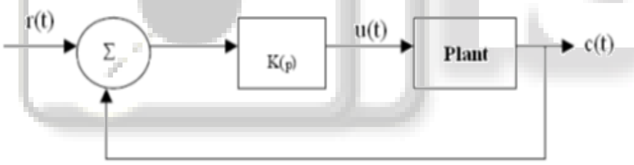

Fig. 2.5: Second Method Control System

Zeigler and Nichols suggested that we set the value of the parameters Kp and Ki according to the formula shown in the Table.

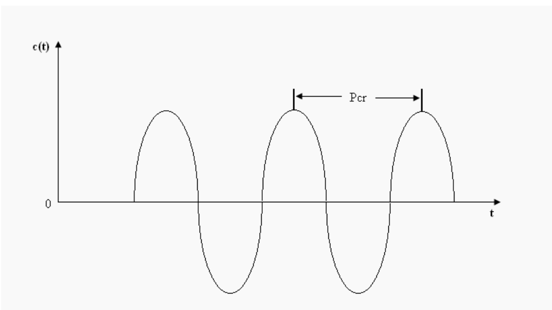

Fig. 6: Position of Pcr

Second method of Zeigler-Nichols rules

Type of controller	K_p	K_i
P	$0.5K_{cr}$	∞
PI	$0.45K_{cr}$	$P_{cr}/1.2$

Notice that the PI controller tuned by the second method of Zeigler-Nichols rules in table gives.

$$G_c(s) = Kp\left(1 + \frac{1}{KiS}\right)$$

$$= 0.45\,Kcr\left(1 + \frac{1}{1.2\,Pcr\,S}\right)$$

III. Fuzzy Logic Controller

Fuzzy logic controller (FLC) is based on fuzzy logic and constitutes a way of converting linguistic control strategy into an automatic control strategy. Fuzzy control is a method based on fuzzy logic. Fuzzy provides a remarkably simple way to draw definite conclusions from a vague ambiguous or imprecise information. It is suitable for application such as the speed control of DC motor which has non linearities. There are specific components characteristic of a fuzzy controller to support a design procedure. The structure of Fuzzy logic controller consists of three major components. First is fuzzifier, which is used for the measurement of the input or definition of the fuzzy set that will be applied. Second is fuzzy control or rule base, which provides the system with the necessary decision making logic based on the rule base that determine the control policy. The third and the last is defuzzifier which combines the actions that have been decided and produce single non-fuzzy output that is control signal of the systems. The fig. 2 below shows controller between the pre processing block and the post processing block.

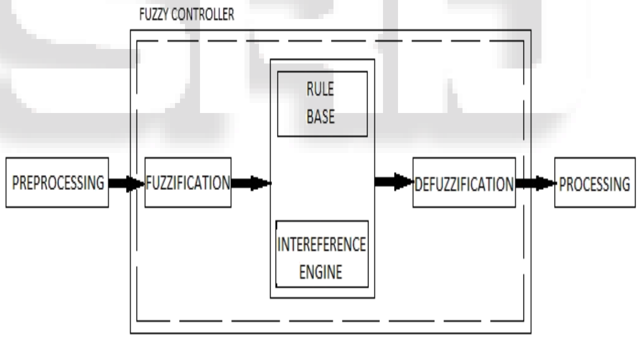

Fig. 7: Structure of fuzzy logic controller

IV. Membership Functions And Rules Of The Fuzzy Controller Used.

The membership functions and the rule base used for the fuzzy controller is as shown in the figure given below.

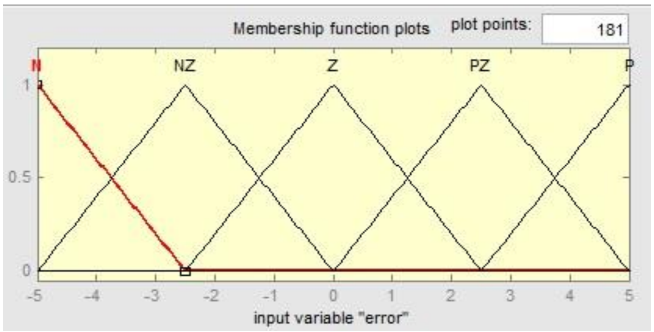

Fig. 8: Input variable “Error”

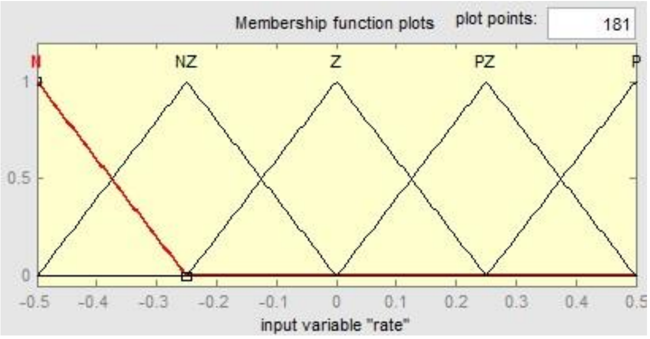

Fig. 9: Input variable “Rate”

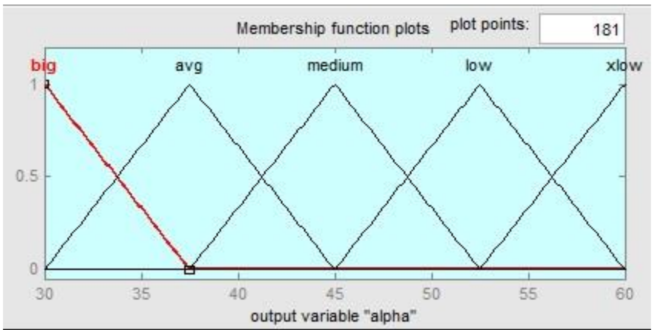

Fig. 10: Output variable “Alpha”

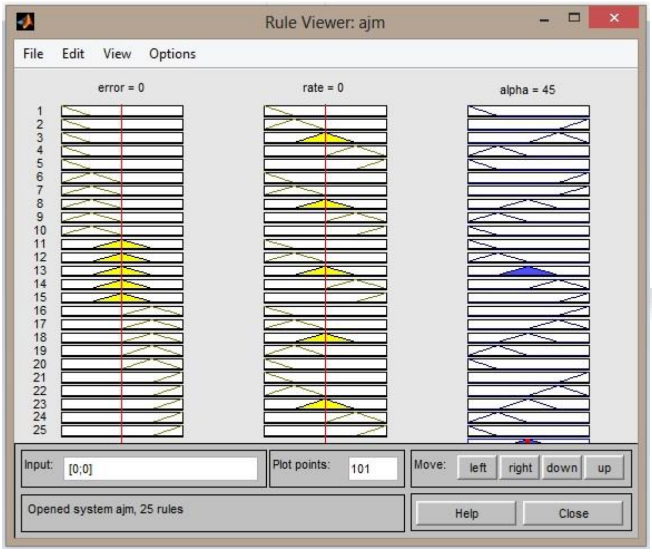

Fig. 11: Rule base

V. SIMULINK MODEL

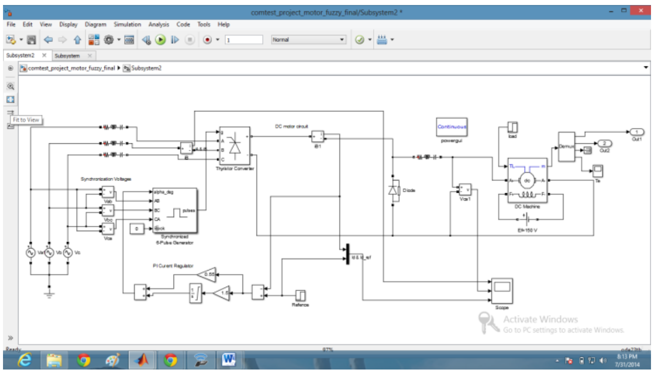

Fig. 12: Speed control circuit with PI controller

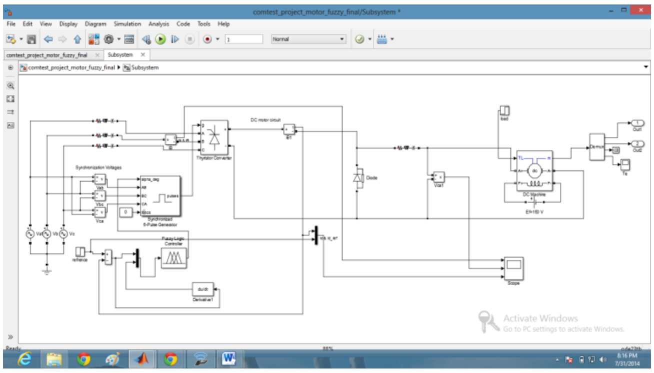

Fig. 13: speed control circuit with FLC

VI. WORKING

The two circuits for the speed control have been shown in the fig.12 and fig.13. Figure 12 shows the close loop operation of the dc motor with PI controller and the figure 13 shows the close loop operation of the DC motor using fuzzy logic controller. A fully controlled thyristor converter is used as the power source for the drive. Output voltage of thyristor convertor can be varied by varying the firing angle of thyristors in bridge circuit. PI controller and Fuzzy logic controller decides the value of firing angle by comparing the reference current and the actual motor current. The pulse generator generates the firing pulses according to the firing angle decided by the fuzzy logic controller. Finally the controlled converter gives the output voltage according to the firing pulses. For the sakeof simplicity the motor used is a separately excited dc motor whose field voltage is set at 150 volts.

The speed of the DC motor is controlled by controlling the output voltage of the fully controlled converter which act as power modulator of system. Again the output voltage is controlled by controlling the firing angle to the thyristor bridge. Relation between output voltage and firing angle is given by the following equation,

$$Vo = \frac{3Vm}{\Pi} \text{Cos}\alpha \qquad (1)$$

Now speed of motor depends on the voltage, the relation between speed and voltage is given by the equation,

$$N = \frac{V - IR}{K\Phi} (2)$$

Here, Vo= output voltage of converter

V_m = peak line to line voltage

α = firing angle

N = motor speed in rpm

I = motor current

R = motor resistor

To control the speed of the motor output voltage V_o is varied keeping the field flux constant. Voltage is controlled by controlling the firing angle. The firing angle is controlled with the help of fuzzy logic controller. The FLC compares the actual current and the rated motor current and gives relative current signal. This current signal is fed to the pulse generator which generates the firing pulses according to the output current of the fuzzy logic controller, and when these firing pulses is fed to the controlled rectifier produces controlled voltage which in turn controls the speed of the motor.

VII. WAVEFORMS & RESULT

The waveforms of current and speed is as shown below in the figure. Fig. 14 represents the variation of current with respect to time with PI controller. It can be clearly seen that the current waveform is not smooth and also it shoot up to 100 amps but on the other hand if we look at fig. 15 it also shows the current waveform using the fuzzy logic controller, the current waveform is much smoother. The peak at the start of the curve is due to the starting current which can be controlled by using a three point or a four point starter. From the two waveforms it can be seen easily that the FLC has improved the system current. The current is in Amp and the time is in second.

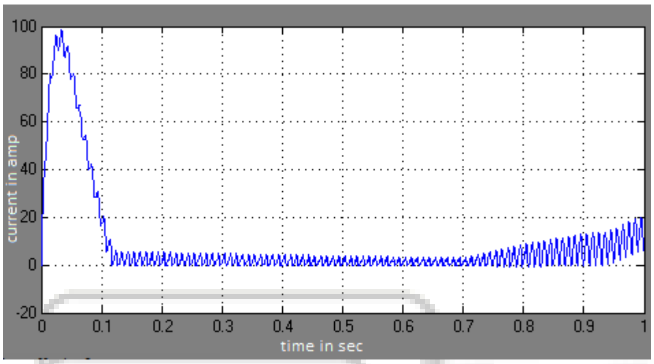

Fig. 14: current time curve of system with PI controller

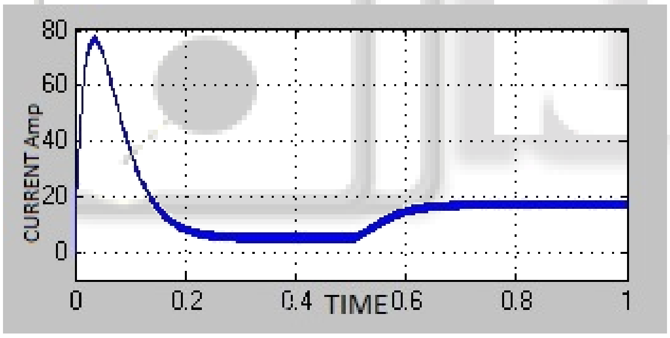

Fig. 15: current time curve with FLC

Fig 16 shows the comparison of current for PI controller fuzzy logic controller and without controller. The blue one is of PI controller, red is of without controller and green colored waveform is of fuzzy lozic controller. The overshoot of blue curve is due to the fast response of pi controller during starting. The fig. 17 on the right side of the page shows the waveform of speed with respect to time. There are three waveforms in the graph, the blue coloured waveform shows the speed variation with time using PI controller. The green coloured waveform shows speed variation with time with fuzzy logic controller and the red one is of without controller. If we look at fig. 17 it can be seen that the blue curve reaches steady state value quickly say around 0.1 secs and if we look the green curve it reaches the steady state value at 0.25 sec. At t= 0.7 sec, the system is loaded to is rated load both the curve shows the sharp decrement in speed but the decrease in speed of green curve is much lesser than the blue curve. Again after loading it can be observed that the green curve reaches to new steady speed quicker than the blue curve. The speed is in rad/sec and time is in sec.

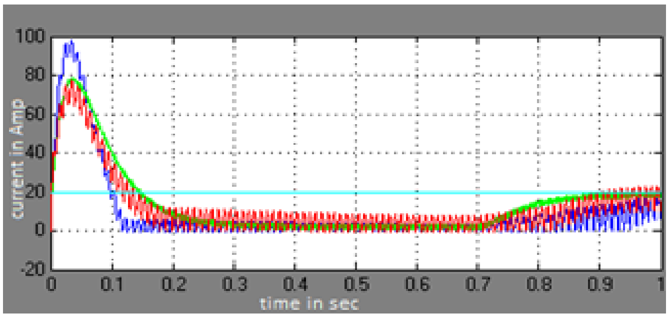

Fig. 16: current comparison

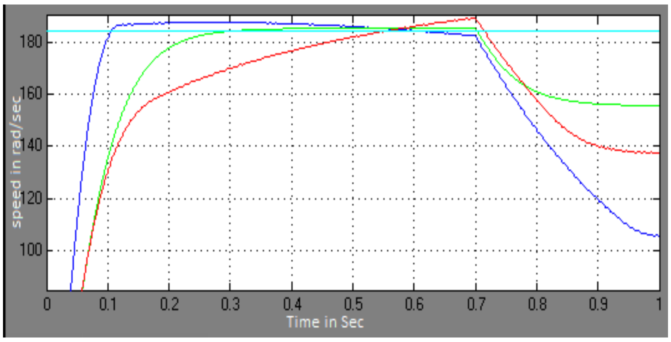

Fig. 17: speed comparison with FLC and without controller

Finally it can be said by observing the above waveforms that, fuzzy logic controller controls the system stability and response better than PI controller.

VIII. CONCLUSIONS

The speed control loop of the drive was simulated with a conventional PI controller in order to compare the performances to those obtained from the respective fuzzy logic based drive system. The dynamic and steady state performance of the fuzzy logic based controlled drive is much better than the PI controlled drives. By using fuzzy logic mode controller for the separately excited DC motor the following advantages have been realized.

(1) Better speed control is obtained.
(2) Reduced over shoot.
(3) Reduced settling time.

Excellent results added to the simplicity of the drive system ,which makes the fuzzy logic based control strategy suitable for a vast number of industrial application, paper mills etc. the sharpness of the speed output with minimum overshoot defines the precision of the proposed drive.They require speed controllers to perform tasks. Hence, a fuzzy based DC motor speed control system was designed using MATLAB.In this paper, a comprehensive analysis of DC drive system has been performed by using fuzzy logic controller. From the output speed wave form, we can see that the speed becomes constant at 0.8 sec for an open loop system while it becomes constant at 0.23 sec for a fuzzy and it becomes stable at 0.1 sec for pi controller. Also in Fuzzy we have a smooth speed control with less overshoot and no oscillations.

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