Fuzzy and PI Controller Based Performance Evaluation of Separately Excited DC Motor

Niraj Kumar Shukla and Dr. S K Sinha

Abstract- **The separately excited dc motors with a conventional PI speed controller are used extensively in industry. This conventional controller can be easily implemented and are found to be highly effective if the load changes are small however, in certain applications, e.g., rolling mill drives or machine tools, the drive operates under a wide range of changing load characteristics and the system parameters vary substantially. A conventional PI or PID controller is not preferable in these applications.**

The development of fuzzy logic controller for dc drives in the present work is inspired by the FLC control strategy. Broadly, two control strategies with fuzzy logic controller are proposed for separately excited dc motor, current control and speed control strategy. The controller is used to generate the firing pulses. The main objective of this work is to reduce the change in speed in transient as well as steady state region. The aim of these proposed schemes are to improve tracking performance of separately excited dc motor and compare with conventional PI control strategy.

Keywords— **Separately excited dc motor, Proportional- Integral (PI), Fuzzy logic controller (FLC), proportional constant (Kp)**

I. INTRODUCTION

The introduction of drive system increases the automation and productivity and also efficiency. The system efficiency can be increased from 15 to 27 % by the introduction of variable speed drive operation in place of constant speed operation. A number of modern manufacturing processes, such as machine tools, require variable speed. This is true for a large number of applications, such as Electric propulsion, Pumps, fan, and compressors,Plant automation ,Flexible manufacturing systems,Robotic actuators, Cement Kilns, Steel mills, Paper and pulp mills, Textile mills .

This paper focuses on the performance evaluation of separately excited dc motor having P-I and fuzzy logic controller. The simulation results are presented to demonstrate the effectiveness of this fuzzy logic and advantage of control system DC motor with fuzzy logic controller (FLC) in comparison with conventional scheme.

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II. SEPARATELY EXCITED DC MOTOR

A separately excited dc motor is one of the most commonly used dc motor. It is represented by equation 1.The equivalent circuit of a dc motor armature is based on the fact that the armature winding has a resistance R_a, a self – inductance L_a, and an induced emf. This is shown in Fig.1. In the case of motor, the input is electrical energy and the output is the mechanical energy, with an air gap torque of T_e at a rotational speed of ω_m.

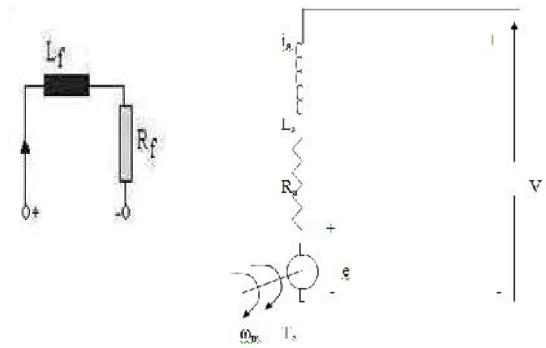

Fig. 1: Equivalent circuit of a dc motor armature

$v = e + R_a i_a + L_a (di_a/dt)$..........1

$v = e R_a i_a$..2

$e = K \Phi_f \omega_m$..3

$T_e = K_b i_a$..4

$K_b = K \Phi_f$ volt/ (rad/sec).............5

where ω_m is rotor speed(rad/sec),v is armature voltage, i_a is armature current, L_a is armature inductance. R_a is armature resistance, K_b and K are motor constants.

The principle of speed control for dc motors is developed from the basic emf equation of the motor. Torque, flux current, induced emf, and speed are normalized to present the motor characteristics. Two types of control are available: armature control and field control. These methods are combined to yield a wide range of speed control.

Modern power converters constitute the power stage for variable-speed dc drives. These power converters are chosen for a particular application depending upon a number of factors such as cost, input power source, harmonics, power factor, noise, and speed of response.A model for the power converter is derived for use in simulation and controller design. Power electronic converters can be found wherever there is a need to modify the form of electrical energy (i.e. modify its voltage, current or frequency).

Armature control has the advantage of controlling the armature current swiftly, by adjusting the applied voltage. . If the supply dc voltage is varied from zero to its nominal value, then the speed can be controlled from zero to nominal or rated value. Therefore, armature control is ideal for speed lower then rated speed; field control is suitable above for speed greater than the rated speed.

Motor Parameters	Value
D.C. motor input voltage	240 V
Armature current rating	16 A
Rated speed	1220 rpm **or** 127.7 rps
Armature resistance R_a	0.5 Ω
Armature Inductance La	0.01 H
Moment of inertia J	0.05 kg – m^2
Viscous friction coefficient B_t	0.02 N.m.s/rad
Load Torque(T_L) (evaluated at steady)	24.178 N-m

TABLE 1: DC Motor Parameter

These rated and evaluated parameters of motor are employed in the simulink model.

III.CONTROLLERS FOR DC DRIVE

The schematic diagram of the dc drive system is shown in Fig. 1. The power circuit consists of a three phase, fully controlled bridge converter that drives a separately excited dc motor.The thyristor bridge converter gets its ac supply through a three phase transformer and fast acting ac contactors. The dc output is fed to the armature of the dc motor.The output of the current controller is the control voltage V_c for the converter firing circuit. The firing pulses for the SCRs are generated with a delay angle, by cosine wave crossing method. The speed and current controllers in Fig. 2 may be P-I controllers or fuzzy logic controllers.

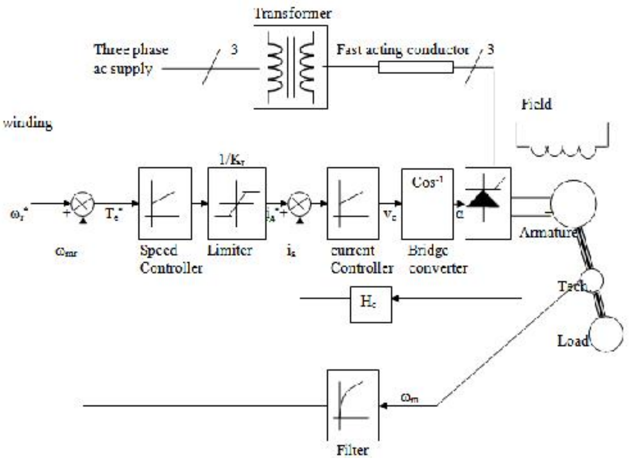

Fig. 2: Speed-controller two-quadrant dc motor drive

The output of the tachogenerator is filtered to remove the ripples to provide the signal, ω_{mr}. The speed command and ω_r^* is compared to the speed signal to produced a speed error signal. This signal is processed through a proportional plus integrator (PI) controlled to determine the torque command. The torque command is limited, to keep it within the safe current limits, and the current command is obtained by proper scaling. The armature current command i_a^* is compared to the actual armature current i_a to have a zero current error. In case there is an error, a PI current controller process it to alter the control signal v_c. The control signal accordingly modifies the triggering angle α to be sent to the converter for implementation.

The inner current loop assures a fast current response and hence also limits the current to a safe preset level. This inner current loop makes the converter linear current amplifiers. The outer speed loop ensures that the actual speed is always equal to the commanded speed and that any transient is overcome within the shortest feasible time without exciding the motor and converter capability.

The inner current loop will maintain the current at level permitted by its commanded value, producing a corresponding torque. As the motor starts running, the torque and current maintained at their maximum level, the accelerating the motor rapidly. When the rotor attains the commanded value, the torque command will settle down to a value equal to the sum of load torque and other motor losses to keep the motor in steady state.

IV. FUZZY LOGIC CONTROL

Fuzzy logic is a thinking process or problem-solving control methodology incorporated in control system engineering, to control systems when inputs are either imprecise or the mathematical models are not present at all. Fuzzy controllers are used in the speed and current loops in Fig.9, replacing the conventional P-I controllers. It is an idea or problem-solving methodology to control non-linear systems. The conventional control systems that work on the basic approximation of systems to be linear systems failed drastically when the range of application of such linear models was increased and therefore the need of control logic that could work even with linear systems was born. . If the dynamics of the system and input parameters are imprecise or missing, then fuzzy logic works by exploiting its tolerance for imprecision of input parameters. As the father of fuzzy logic Lofti A Zadeh puts it, "because precision is costly, it makes sense to minimize the precision needed to perform a task." The applicability of fuzzy logic is indeed promising

To specify rules for the rule-base, the expert will use a "linguistic description"; hence, linguistic expressions are needed for the inputs and outputs and the characteristics of the inputs and outputs. "linguistic variables" (constant symbolic descriptions of what are in general time-varying quantities) are used to describe fuzzy system inputs and outputs. For our fuzzy system, linguistic variables denoted by ˜*ui* are used to describe the inputs *ui*. Similarly, linguistic variables denoted by ˜*yi* are used to describe outputs *yi*. For instance, an input to the fuzzy system may be described as ˜*u*1 = "position error" or ˜*u*2 = "velocity error," and an output from the fuzzy system may be ˜*y*1 ="voltage in."

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy (crisp to fuzzy). By identifying some of the uncertainties present in the crisp values, we form the fuzzy values. The conversion of fuzzy values is represented by the membership functions. In any practical applications, in industries, etc., measurement of voltage, current, temperature, etc., there might be a negligible error. This causes imprecision in the data. This imprecision can be represented by the membership functions. Hence fuzzification is performed. Thus fuzzification process may involve assigning membership values for the given crisp quantities.

Defuzzification is the conversion id a fuzzy quantity to a crisp quantity, just as fuzzification is the conversion of a precise quantity to a fuzzy quantity. The output of a fuzzy process can be the logical union of two or more fuzzy membership functions defined on the universe of discourse of the output variables

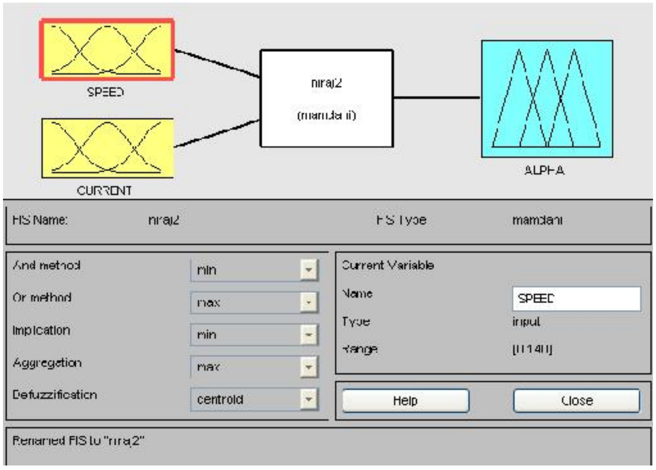

Fig. 3: FIS editor of fuzzy controller with 9 rule base

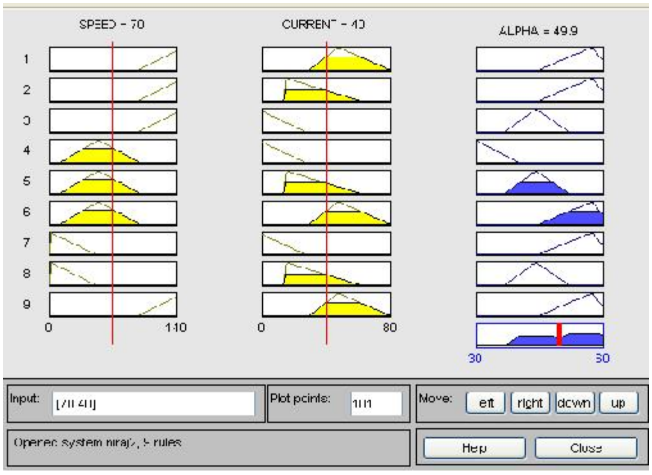

Fig. 4: Rule viewer of fuzzy controller with 9 rule base

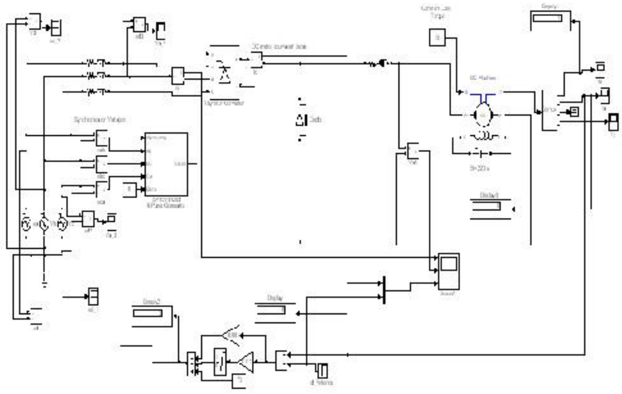

Fig.5. System model with current control strategy

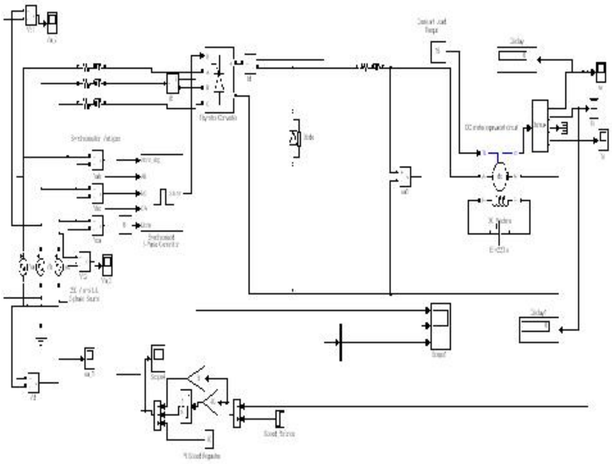

Fig.6: System model with speed control strategy

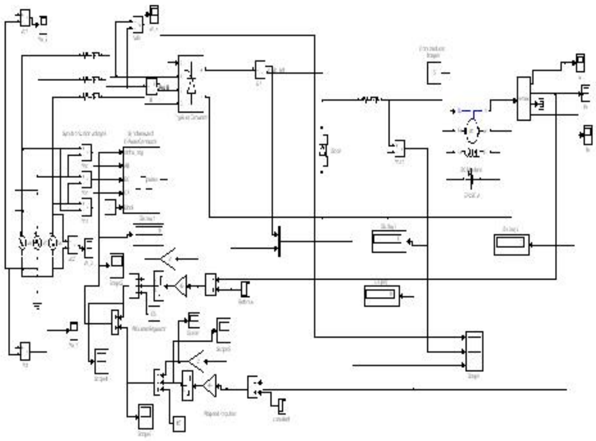

Fig.7: System model with current control and speed control strategy

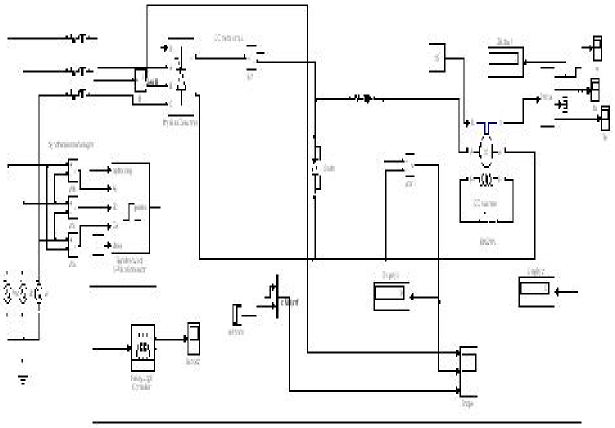

Fig.8: Simulink model of plant having fuzzy controller with 3&5 rule base

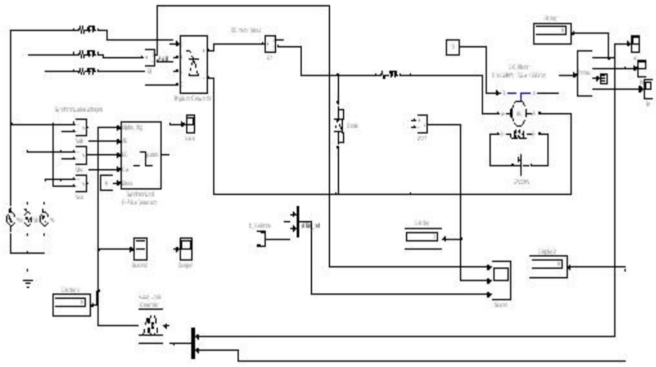

Fig.9: Simulink model of plant having fuzzy controller with 9 rule base

RESPONSE OF DRIVE CONTROLLED BY PI CURRENT CONTROLLER

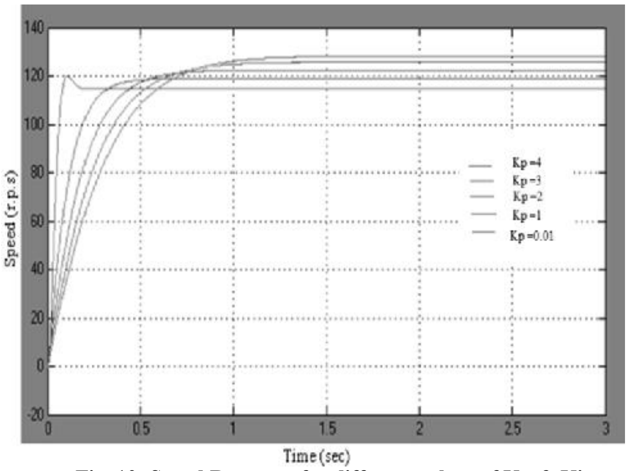

Fig. 10: Speed Response for different values of Kp & Ki

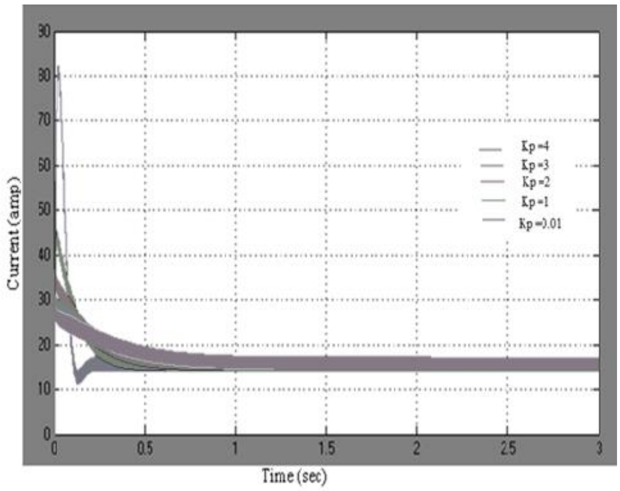

Fig.11: Current Response for different values of Kp & Ki

RESPONSE OF DRIVE CONTROLLED BY PI SPEED CONTROLLER

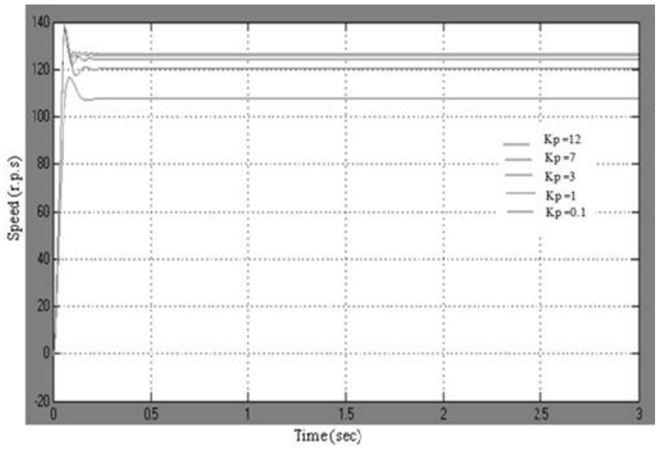

Fig.12: Speed Response for different values of Kp & Ki

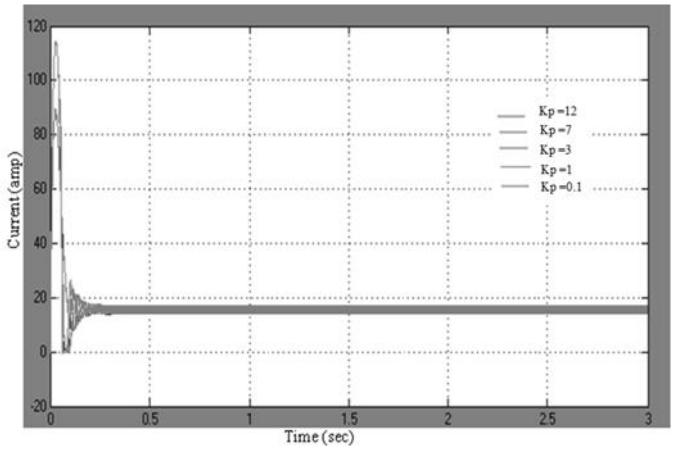

Fig.13: Current Response for different values of Kp & Ki

RESULTS OF DRIVE CONTROLLED BY PI CURRENT AND SPEED CONTROLLER STRATEGY BOTH

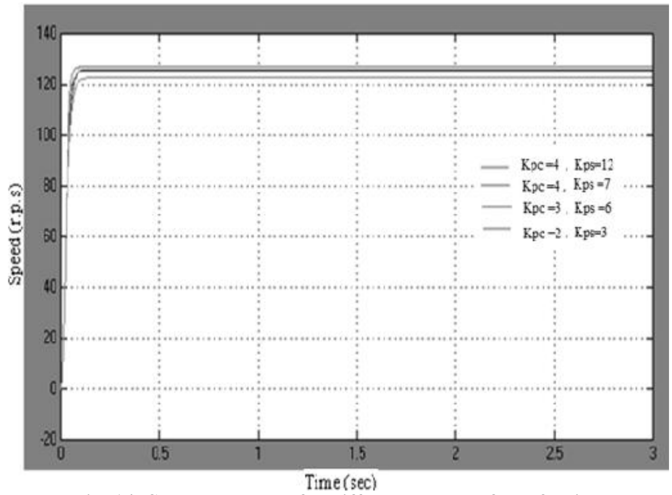

Fig. 14: Speed Response for different values of Kp & Ki

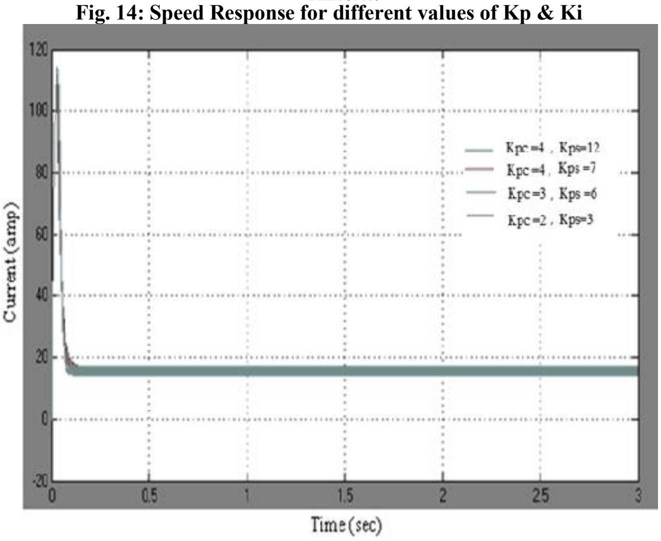

Fig.15: Current Response for different values of Kp & Ki

FUZZY CONTROLLER APPROACH

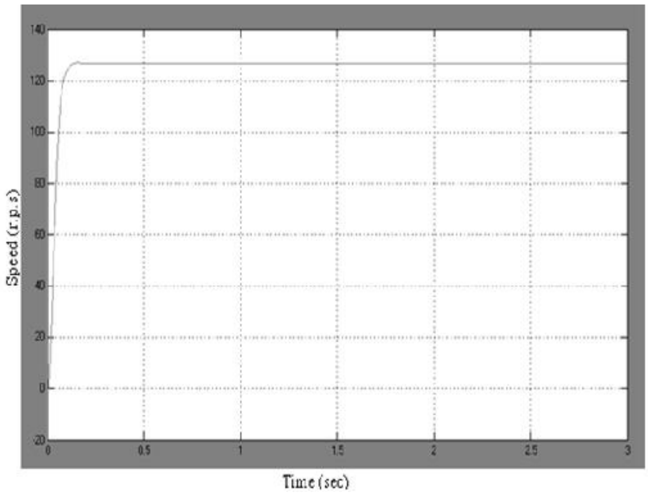

Fig.16: Speed Response for 3 rule base

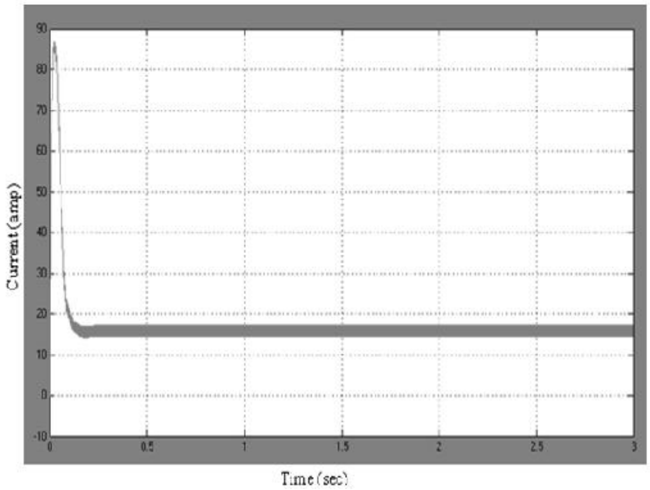

Fig.17: Current Response for 3 rule base

It is observed that, for 3 rule base overshoot is 0.31% and settling time is 0.27 sec.

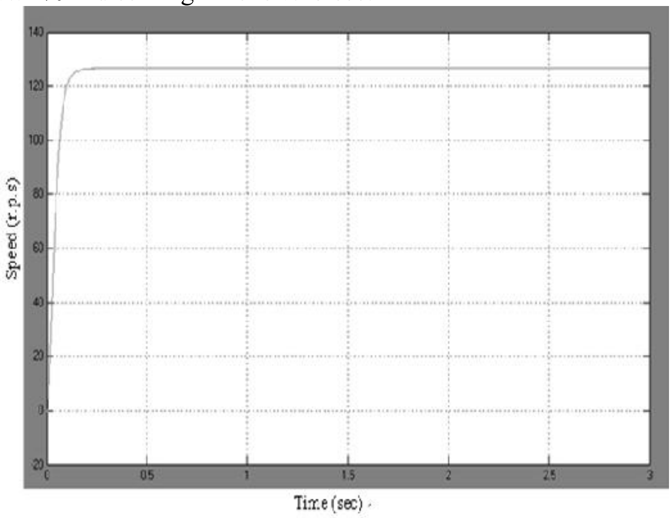

Fig. 18: Speed Response for 5 rule base

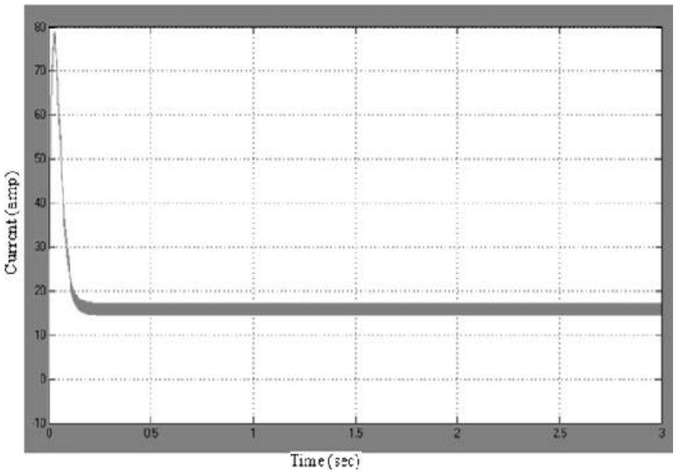

Fig. 19: Current Response for 5 rule base

The result observed for 5 rule base is that, it has no overshoot but settling time is increased from 0.27 secs to 0.40 secs.

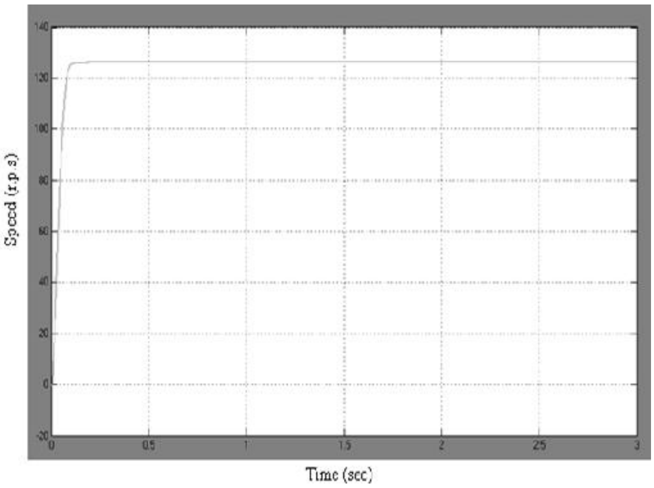

Fig. 20: Speed Response for 9 rule base

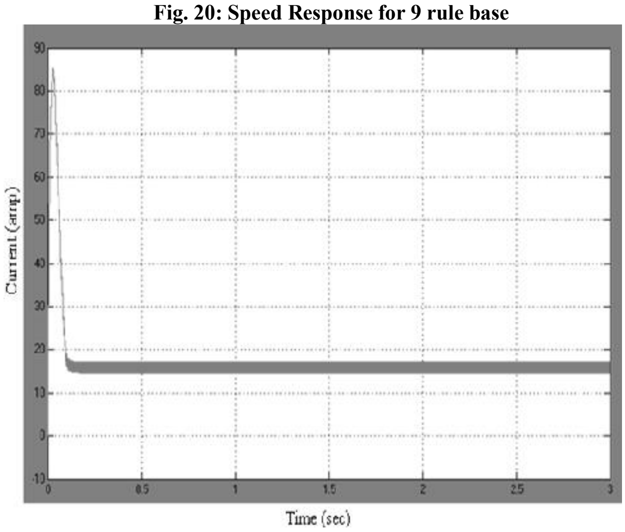

Fig.21: Current Response for 9 rule base

The result of 9 rule base shows that overshoot is reduced to a great extent keeping settling time to merely 0.30 sec.

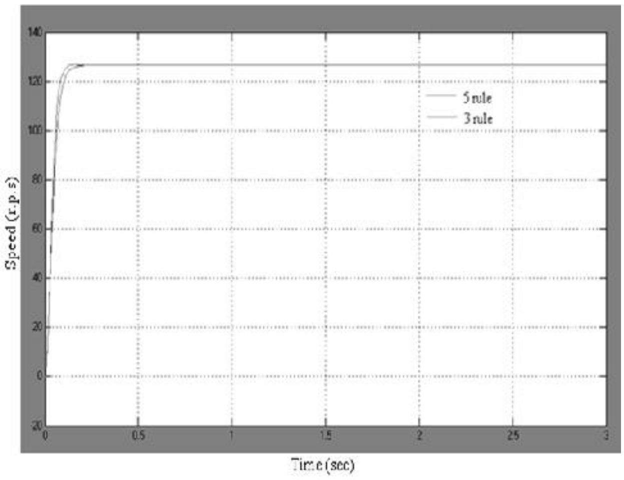

Fig.22: Speed comparison for plants having fuzzy controller with 5 rule base vs. 3 rule base

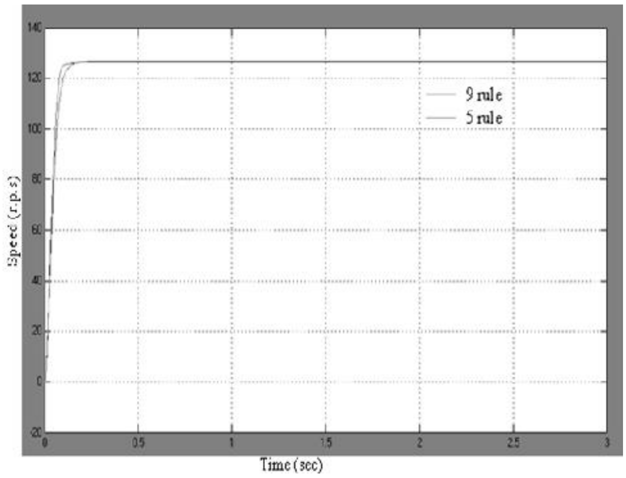

Fig.23: Speed comparison for plants having fuzzy controller with 9 rule base vs. 5 rule base

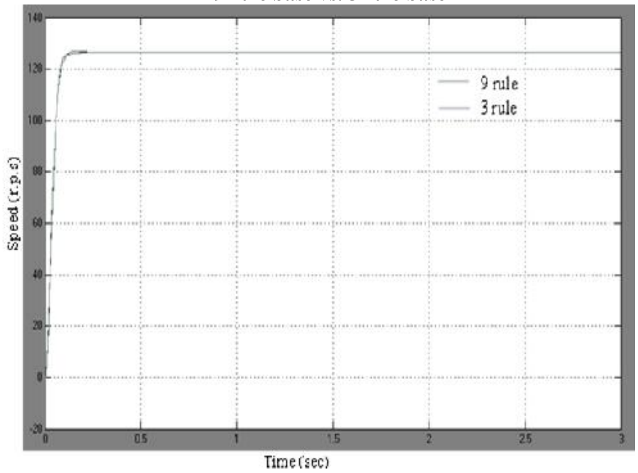

Fig.24: Speed comparison for plants having fuzzy controller with 9 rule base vs. 3 rule base

V. RESULT ANALYSIS

Plant description	Maximum % Overshoot (% Mp)	Settling Time (ts in secs)	Speed regulat ion	Current (amp)
Plant with uncontrolled rectifier	4.85%	0.47	1.51%	16.2
Plant having PI current controller for kp = 3 and ki = 0.00001	--	2.2	1.51%	16.19
Plant having PI speed controller for kp = 12 and ki = 0.00001	10.10 %	0.42	0.71 %	16.14
Plant having PI current & speed controller for kpc=4, kps=12 & ki=0.00001	--	0.22	0.95 %	16.18
Plant having fuzzy controller with 3 rule base(current)	0.31%	0.27	0.86%	16.16
Plant having fuzzy controller with 5 rule base(current)	0.03%	0.4	0.71 %	16.15
Plant having fuzzy controller with 9 rule base(current and speed)	--	0.3	0.86 %	16.16

Table.2: Result analysis for different drive models

From the table 2 above, it is observed that excellent results are obtained by use of fuzzy controller for dc drive system with optimum performance achieved through 9 rule base. Overshoot can also reduced by using 5 rule base and 3 rule base but the disadvantage is that it results in increased settling time , poor speed regulation and increased losses when compared to fuzzy controller with 9 rule base.

The results obtained by simulation of plant with uncontrolled converter shows poor speed regulation, settling time and had high overshoots in transient region. In order to reduce the maximum overshoots the uncontrolled converter is replaced with a controlled one whose firing is controlled with the help a PI controller. It is observed that for various values of proportional and integral gain, the overshoots get reduced to a great extent as compared to the plant with uncontrolled model. On the other hand, the use of PI controller in uncertainty association as load increases the settling time and speed regulation are not as per desirable one. This situation is overcome by replacement of PI controller with fuzzy logic controller. It is observed that using fuzzy controller of Mamdani model with 9 rule base; the maximum overshoot gets reduced with less settling time, gives better efficiency and better speed regulation.

VI. CONCLUSION

It is observed that fuzzy controller with Mamdani model for 3 rule base, 5 rule base and 9 rule base can minimize the peak overshoot ,settling time and shows better speed regulation on contrary to conventional cases. With 9 rule bases, a significant improvement is achieved in view of overshoot, settling time along with better speed regulation and better drive efficiency.

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