Performance Analysis of Fuzzy Logic Controller Based DC-DC Converter fed DC Series Motor

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Abstract: A fuzzy controller for closed loop control of DC drive fed by DC-DC converter (Chopper) is designed and presented in this paper. This system has been designed to have two loops with an inner ON/OFF current controller and an outer fuzzy speed controller. The later is used to change the duty cycle of the converter and thereby, the voltage fed to the DC series motor regulates its speed. The performance in respect of load variation and speed change has been reported. The performance o f the proposed controller is compared with the reported results and found that the fuzzy based DC-DC drive can have better control.

Key Words: — DC-Series Motor, fuzzy controller, DC-DC Converter, speed control

1 INTRODUCTION

In recent years, the fuzzy logic/set theory has been utilized for various control applications including motor control. The fuzzy logic has made the control of complex non linear systems with unknown or un-modeled dynamics as simple as possible [1]. The application of DC motor in industrial environment has increased due to the high performance and high starting torque as suitable drive system. There have been several conventional control techniques in DC motor drives are presented [2] and [3]. In earlier conventional control strategies were used and it comprises of fixed arrangement with fixed parameter design. Hence the tuning and optimization of these controllers is a challenging and difficult task, particularly, under varying load conditions, parameter changes, abnormal modes of operation.

Senthil Kumar et.al [4] have demonstrated the separately excited dc motor fed by a chopper (DC to DC converter) and controlled by a fuzzy logic controller. It has been reported that the fuzzy logic controller controls the duty cycle of the chopper, there by the voltage fed to the motor for regulating the speed. The experimental setup has improved the performance over PI controller. It is seen that the separately excited dc drive have low starting torque which limits its applications.

H.A.Yousef and H.M.Khalil [5] have reported the dc series motor drive fed by a single phase controlled rectifier (AC to DC converter) and controlled by fuzzy logic. It has been concluded that the fuzzy logic controller provides better control over the classical PI controller which has improved the performance. It is also reported that the settling time and maximum overshoot can be reduced. Due to the inherent limitations, AC to DC converter fed drive introduces unwanted harmonic ripples in the output.

H.L.Tan [6] has reported the dc series motor drive fed by a single phase full-bridge converter (DC to DC converter) controlled by fuzzy logic. It has been reported that the motor performance was simulated for different controllers like simplify fuzzy logic model (SFL), PI type fuzzy controller (FPI) and classical PI controller. The simulation result shows that the SFI provides superior performance over other controllers. It is found from the analysis that only the speed error has been taken as fuzzy input.

The proposed system utilizes the fuzzy logic controller and DC to DC converter. The drive system has the characteristics of precise, fast, effective speed reference tracking with minimum overshoot/undershoot and minimal steady state error. The fuzzy logic based speed command profile is followed even under load torque disturbances. In order to control the speed of such drive while maintaining the current at a limiting value, a fuzzy speed and ON/OFF current controllers have been designed.

2 PROPOSED SYSTEM

Figure 1 shows the block diagram of the proposed system. The system consists of DC-DC converter to drive the DC motor. A tacho generator is used to sense the speed and which is used for speed feedback. A micro-controller or a digital signal processor is used to generate the PWM signal to switch the DC-DC converter, during the implementation of experimental setup.

The system two loops consist of namely outer fuzzy speed control loop and inner ON/OFF current control loop. In outer speed control loop, the actual speed (ω) is sensed by tacho generator and the error signal is obtained by comparing with reference speed (ω_r). From the present error and pervious error the change in error is calculated.

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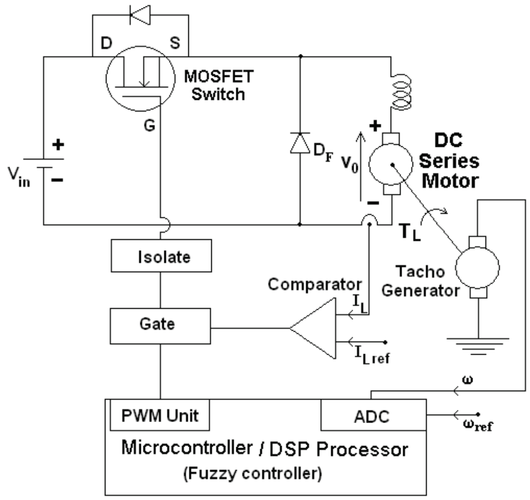

Fig 1. Block diagram of the proposed system

In the proposed system two input fuzzy controllers are used. The error and change in error are given as inputs to the fuzzy logic controller. The output of the fuzzy controller is denoted as duty cycle[7].

3 MATHEMATICAL MODELING OF DC SERIES MOTOR AND DC-DC CONVERTER

3.1 DC Series Motor

The proposed system can be simulated with proper mathematic modeling. The DC motor can be written in terms of equations as follows [5].

$$\frac{di_a}{dt} = \frac{1}{L_a}\left[V_o - R_a i_a - K_{af} i_a \frac{d\theta}{dt} - K_{res}\frac{d\theta}{dt}\right] \quad (1)$$

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}\left[K_{af} i_a^2 - B\frac{d\theta}{dt} - T_L\right] \quad (2)$$

where

i_a=i_{se} - Motor current
V_0 - Motor terminal voltage
R_a - Armature resistance
L_a - Armature inductance
J - Moment of inertia
B - Friction coefficient
T_L - Load torque
$\omega = \frac{d\theta}{dt}$ - Angular speed
θ-Angular displacement
K_{af} - Armature voltage constant and
K_{res} - Residual magnetism voltage constant

The non linear equations can be simulated with simulink as given in Figure 2. A nonlinear controller is desired to control the speed of the modeled DC motor. The fuzzy logic controller is the one of the best suited non linear controller, to control the DC motor [4].

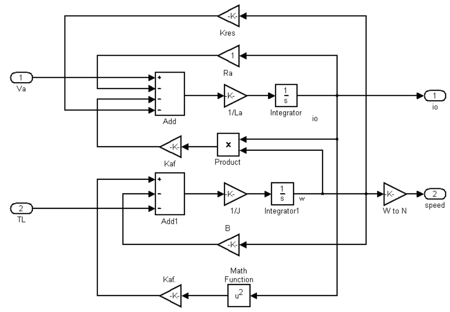

Fig 2. Simulink model of DC series motor

3.2 DC-DC Converter

The DC-DC converter switch can be a Power Transistor, SCR, GTO, and IGBT, Power MOSFET or similar switching device. In order to get high switching frequency (upto 100 KHz) the Power MOSFET may be taken as a switching device. Normally on state drop in the switch is small and it is neglected [8].

When the gate pulse is applied the device is turned on. During the period the input supply connects with the load. When the gate pulse is removed the device is turned off and the load disconnected from the input supply.

The model equation for DC-DC converter is given by

$$V_o = \delta V_s \quad (3)$$

$$\delta = \frac{T_{ON}}{T} \quad (4)$$

$$T = T_{ON} + T_{OFF} \quad (5)$$

where V_0 – Output Voltage
V_S – Input Voltage
T_{ON} – ON Time
T_{OFF} – OFF Time
T – Total Time
δ - Duty Cycle

4 IMPLEMENTATION OF FUZZY CONTROLLER IN MATLAB / SIMULINK

4.1. Fuzzy Logic Control (FLC)

The effective and efficient control using fuzzy logic has emerged as a tool to deal with uncertain, imprecise or qualitative decision making problems [9 to 15].

The FLC involves three stages namely Fuzzification, Rule-Base and Defuzzification. The Sugeno type controller is performed for present control because it has singleton membership in the output variable. Moreover it can be easily implemented and number of calculations can be reduced [7].

4.2. Fuzzification

In Fuzzy logic system the linguistic variables are used instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) in to a linguistic variable (fuzzy number or fuzzy variable) is called fuzzification.

In this work, the motor variables are speed and current (i_a). The speed is controlled by FLC. The error e(k) and change in error Δe(k) is given as input to the FLC. The error is found by comparing the actual speed ω(k) with reference speed ω_r(k). From the error e(k) and pervious error $e_{pervious}$(k) the change in error Δe(k) is calculated and then it is normalized, in order to use the same FLC for different reference speed. Then the error and change in error are fuzzified. The equation for error and change in error are given in equation 6 and 7 [14].

Seven linguistic variables are used for the input variable e(k) and Δe(k). That are negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM) and positive big (PB). There are many types of membership functions, such as triangular-shaped, Gaussian, sigmoidal, pi-shaped trapezoidal-shaped, bell-shaped etc. the triangular membership function is used for simplicity and also to reduce the calculations [5] and [7].

$$e(k) = \varpi_r(k) - \varpi(k) \qquad (6)$$

$$\Delta e(k) = e(k) - e_{Pervious}(k) \qquad (7)$$

4.3. Defuzzification

The reverse process of fuzzification is called defuzzification. The linguistic variables are converted in to a numerical variable [5]. As the weighted sum method is considered to be the best well-known defuzzification method, it is utilized in the present model.

The defuzzified output is the duty cycle dc(k). The change in duty cycle Δdc (k) can be obtained by adding the pervious duty cycle pdc(k) with the duty cycle dc(k) which is given in equation 8.

$$\Delta dc(k) = dc(k) + pdc(k) \qquad (8)$$

The input and output fuzzy membership functions are shown in Figure 3.

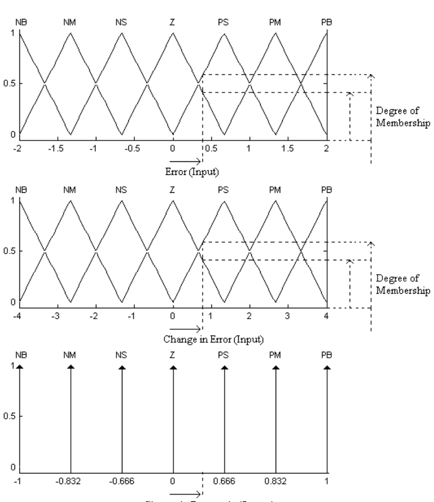

Fig 3. Fuzzy memberships used for simulation

4.4. Rule Table and Inference Engine

The control rules that relate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behavior, also the perception and experience. However, some of the control rules are developed using "trial and error" method [16].

The general rule can be written as

If e(k) is X and Δe (k) is Y, then Δdc(k) is Z

where X, Y and Z are the fuzzy variable for e(k), Δe(k) and Δdc(k) respectively [6].

The rule table for the designed fuzzy controller is given in the Table 1. [7]. The element in the first row and first column means that

If error is NB, and change in error is NB then output is NB.

Table1. Fuzzy Rules

Change in Error \ Error	**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

5 SIMULATION OF THE PROPOSED SYSTEM

The simulation of DC-DC converter fed dc series motor is done based on equation modeling technique, using MATLAB/simulink toolbox. The complete simulink model developed is given in Figure 4.

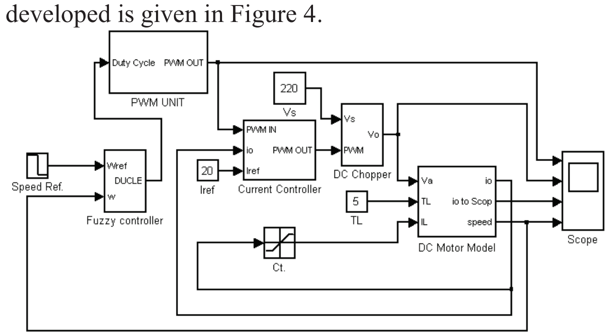

Fig 4. Simulink Model of the proposed system

The fuzzy controller block from fuzzy logic toolbox is used to test and evaluate the proposed fuzzy controller.

6 RESULTS AND DISCUSSION

The proposed model has been simulated using Matlab simulink toolbox. The fuzzy controller has been designed and DC-DC converter was tested. The simulated waves with MATLAB of input gate Pulse, Output Voltage, Motor Current and Speed with respect to time for ω_r=1800 rpm are shown in Figure 5. The expanded view is shown in Figure 6.

The proposed model including fuzzy controller and DC-DC converter has been simulated using MATLAB simulation. The specification of DC series motor used for simulation is given in Table 2.

Table2. DC Motor Specifications

DC motor Parameters	Value
Motor Rating	5HP
Dc supply voltage	220 V
Motor rated Current	18 A
Inertia constant J	0.0465 Kg-m^2
Damping constant B	0.004 N.m.Sec./rad
Armature resistance R_a	1Ω
Armature inductance L_a	0.032 H
Motor Speed	1800 rpm
Armature voltage constant K_{af}	0.027 H
Residual magnetism voltage const. K_{res}	0.027 V.Sec./rad

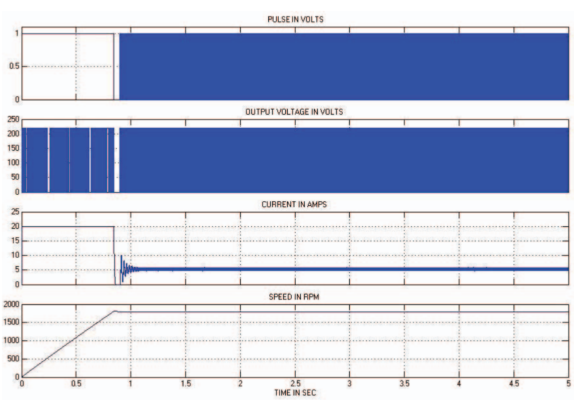

Fig 5. Pulse, Output Voltage, Motor Current and Speed Variation with respect to Time Response for ω_r=1800 rpm

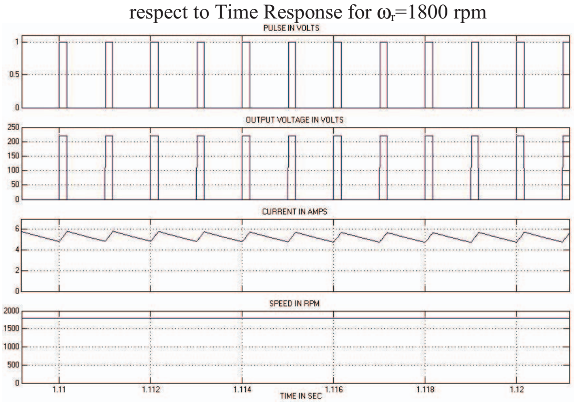

Fig 6. Expanded view of Pulse, Output Voltage, Motor Current and Speed Variation with respect to Time Response for ω_r=1800 rpm

The speed variation with respect to time and Current Variation with respect to time is shown in Figure 7 and Figure 8 respectively. The performance comparison of proposed system with the reference [5] is given in Table 3.

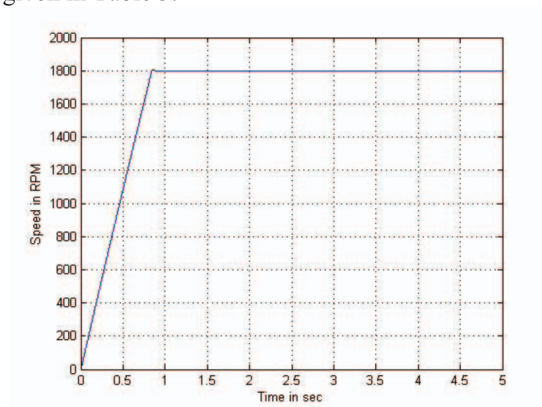

Fig 7. Speed Variation with respect to Time Response for ω_r=1800 rpm

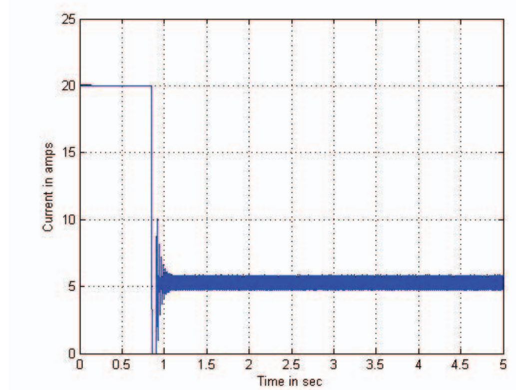

Fig 8. Motor Current Variation with respect to Time Response for ω_r=1800 rpm

Table 3. Performance Comparison of proposed system with the reference [5] for the speed ω_r=1800 rpm

Controller	**Fuzzy [5]**	**Classical PI [5]**	**Fuzzy Proposed System**
Settling time	1.7 Sec	2.67 Sec	1 Sec
Max. over Shoot	3.21%	6.72%	0.36%

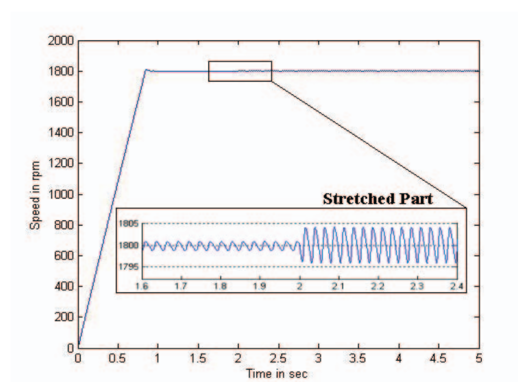

Fig 9. Speed variation for the step change in load torque (ΔT_L=25%) applied at t=2secs when the speed is 1800rpm.

The simulated result of speed regulation for a step change in the load torque of 25%, 50% and 75% applied at t=2 sec is shown in Figure 9, Figure 10, and Figure 11 respectively. From these figures, it is clear seen that the load influences the performance of the controller and hence the motor

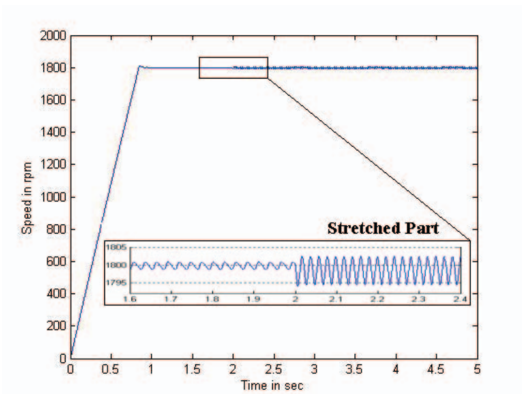

Fig 10. Speed variation for the step change in load torque (ΔT_L=50%) applied at t=2secs when the speed is 1800rpm.

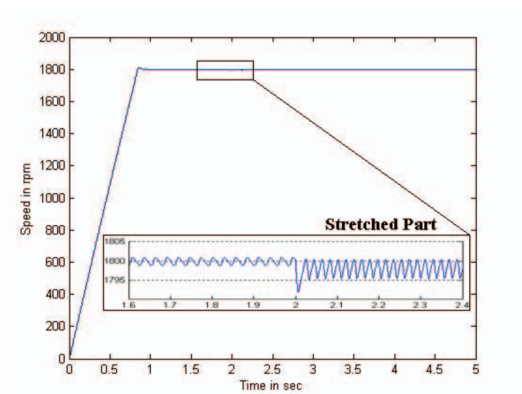

Fig 11. Speed variation for the step change in load torque (ΔT_L=75%) applied at t=2secs when the speed is 1800rpm.

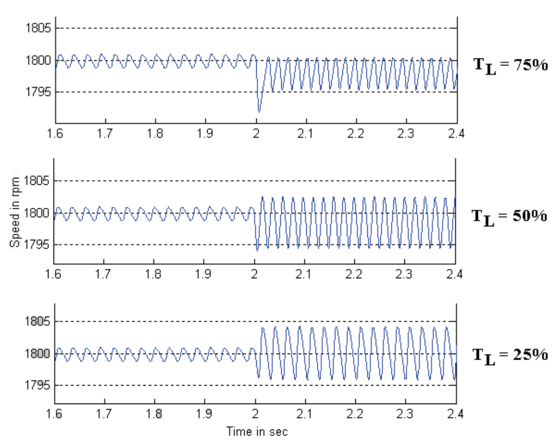

Fig 12. Comparison of Speed variation for the step change in load torque (ΔT_L=25%,50% and 75%) applied at t=2secs when the speed is 1800rpm.

From Figure 12 it is evident that the motor speed is function of the load torque and seen that when load is applied the motor takes it is sufficient time to reach the specified speed. The performance under various load condition is given in Table 4.

Table4. Comparison of Speed variation under various load condition

Load	Variations in speed (rpm)	Speed Drop	Recovery Time (msec)
No Load	2	-	-
25%	8	0.2%	11
50%	7	0.3%	13
75%	6	0.4%	23

The Performance Comparison of proposed system with the work reported in [5] is given in Table 5.

Table5. Performance Comparison of proposed system with [5] for the speed ω_r=1800 rpm and ΔT_L=5 N.m applied at t=2secs

Controller	Fuzzy [5]	Classical PI [5]	Proposed System
Max. over Shoot	3.21%	6.72%	0.36%
Max. Speed Drop	3.5%	5.26%	0.3%
Recovery time	2.4 Sec	2.82 Sec	0.01 Sec

The speed variation and the behavior of the system is given in Figure 13. It is seen from figure that when the speed is increased from 1000rpm to 1800rpm the motor takes 0.7sec whereas in the initial stage it took almost 0.8 sec to reach 1000rpm. This may be due to the inertia in the beginning. The set speed change is achieved with minimum transition time for both the case from lower speed to higher speed and higher speed to lower speed.

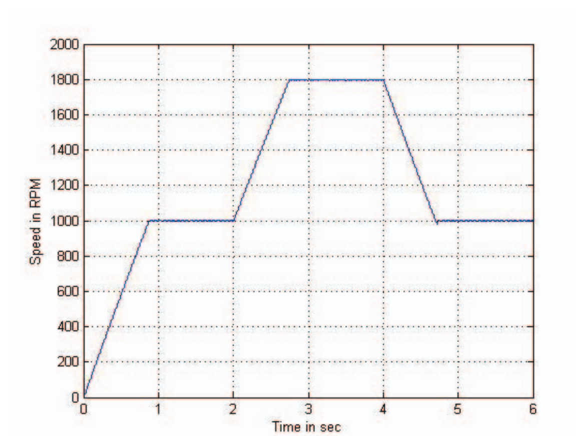

Fig 13. The variation of speed for the step change in set speed from 1000 to 1800rpm and 1800 to 1000 RPM with rated load.

The speed Variation with respect to time and the current variation with respect to time for the reference speed 764rpm(ω_r = 80 rad /sec) is shown in Figure 14 and Figure 15 respectively. Comparing with [6], the proposed controller settling time is less (0.44 sec) than that the controller settling time (0.91sec for SFL) [6]. Moreover the proposed system is simulated for higher power rating machine and the motor parameters are shown in the Table 3.

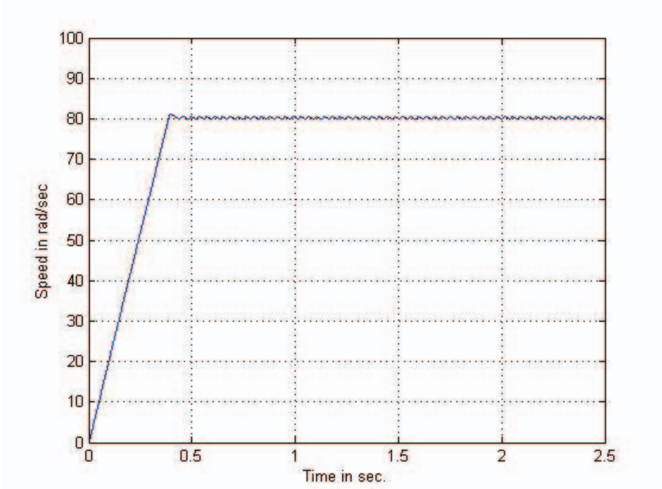

Fig 14. Speed Variation with respect to Time Response for ω_r=80rad/sec

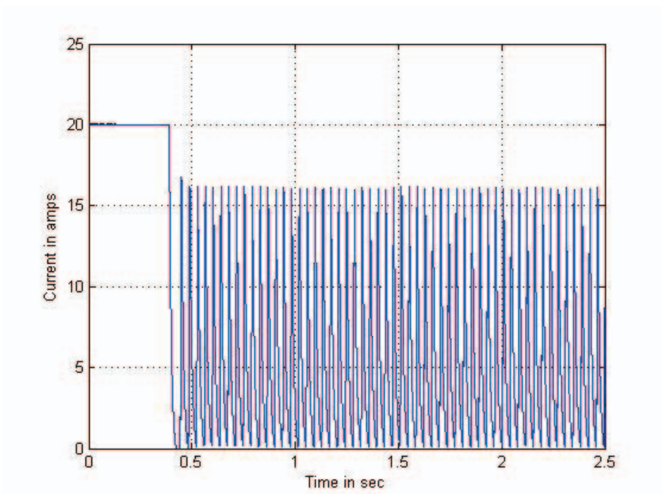

Fig 15. Motor Current Variation with respect to Time Response for ω_r=80rad/sec

7 CONCLUSION

The performance of the two input fuzzy logic controlled DC-DC converter fed DC series motor is presented in this paper. The dynamic speed response of DC series motor with fuzzy controller was estimated and found that the speed can be controlled effectively. The analysis provides the various useful parameters and the information for effective use of proposed system.

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