A Fuzzy Logic based Robust Speed Controller for Chopper Fed DC Motor Drive

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ABSTRACT
Proportional-Integral (PI) controllers are conventionally used in speed control applications of dc drives. These controllers provide good steady state response but do not provide better dynamic response during transient conditions. In this paper an effort is made to design a fuzzy logic controller (FLC), which can provide a better dynamic as well steady state response for speed control application of dc drives. In this work a chopper fed separately excited dc motor is used for speed control application. The simulation results confirm the effectiveness of proposed FLC as the dynamic response has improved tremendously with less torque and armature current ripples.

Keywords
Dynamic response, fuzzy logic controller, torque ripples, steady state response, universe of discourse

1. INTRODUCTION
The technology of speed control of dc drives has advanced considerably with the exponential growth in solid state converters. The converters used for speed control applications are controlled rectifiers or choppers. Different control strategies have been implemented to regulate the dc-dc converter including PI, FLC and sliding mode control [1], [2].
Development of a high performance, robust and reliable speed controller for dc drives is a field of interest for many researchers. Conventionally PI controllers are used in speed control applications. Although these controllers provide excellent steady state characteristics but during load change or change in reference speed the large overshoot and settling time makes the dynamic response slightly inferior. These controllers are more sensitive to parameter variations and sudden change in loading conditions. In last few decades FLC based control schemes have attracted the researchers due to their inherent capability to handle imprecisely defined systems.
In this work an FLC is designed for speed control of a chopper fed separately excited dc motor. By controlling the gate pulse of chopper the output voltage can be varied, this variable dc voltage is applied to the armature terminals of the dc motor to obtain variable speed.

2. CHOPPER FED DC MOTOR DRIVE
A chopper converts fixed voltage dc supply into a variable voltage dc supply. A schematic diagram of a chopper connected with a separately excited dc motor is shown in Fig. 1(a). The chopper is a high-speed on-off switch as shown in Fig. 1(b) [3], [4]. When the switch S is closed i.e. the chopper is on, v_t=V and motor current i_a starts increasing and when it is off, motor current decays through the diode D, making v_t=0.

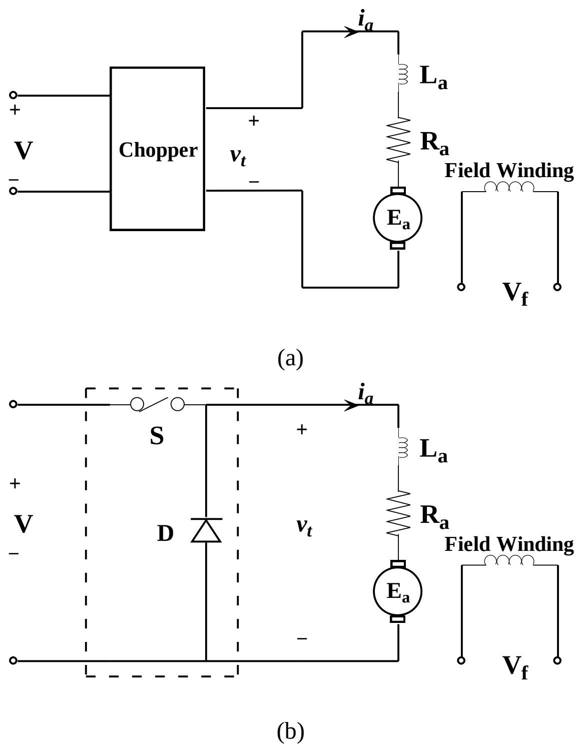


Fig.1. Chopper fed separately excited dc motor (a) schematic diagram (b) circuit diagram

The average output voltage V_t, which determines the speed of the dc motor [3], is

$$V_t = \frac{t_{on}}{T} V = \alpha V \quad (1)$$

where, t_{on} is the on time of chopper,
T is the chopping period, and
α is the duty ratio of the chopper.
From eq. (1) it is clear that the average motor terminal voltage varies linearly with the duty ratio of the chopper.

3. CLOSED LOOP OPERATION

The basic block diagram of a closed loop speed control scheme is shown in Fig.2.

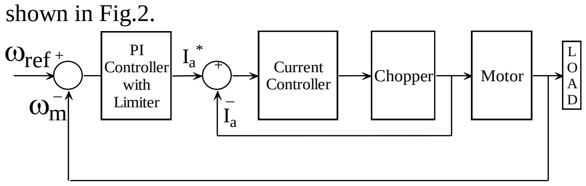


Fig.2. Block diagram of closed loop control scheme

The reference speed is compared with the actual motor speed, error signal between the two speeds is processed through the conventional PI controller and a limiter to obtain a reference current signal. The purpose of limiter is to limit the reference armature current so that it does not go beyond the safe operating value. The reference current so obtained is then compared with the actual armature current, depending upon the difference between these two currents a hysteresis current controller generates gate pulse for the chopper. By controlling the duty ratio of chopper through gate pulses, the output voltage of chopper is controlled. This controlled voltage is fed to armature terminals of dc motor to get a controlled speed. To understand the operation, let an additional load torque is applied the motor speed momentarily decreases and the speed error increases [3]. This results in an increase in control signal, which is responsible for increased duty cycle of chopper and hence increased armature terminal voltage. An increase in motor armature voltage develops more torque to restore the speed. The system thus passes through a transient period till the developed torque matches the applied load torque.

4. FUZZY LOGIC CONTROLLER

Fuzzy logic is the branch of artificial intelligence that deals with the reasoning algorithms used to emulate human thinking and decision making in machines. The FLC provides a method of converting a linguistic control strategy based on expert knowledge into an automatic control strategy [5].

It was Lotfi A. Zadeh who propounded the fuzzy set theory in his seminal paper. The pioneering research of Mamdani and his colleagues of fuzzy control was motivated by Zadeh's seminal papers on the linguistic approach and system analysis based on the theory of fuzzy sets.

4.1 Proposed fuzzy control scheme

In the proposed fuzzy control scheme, the actual speed of dc motor is sensed and then compared with the reference speed. The error 'e' between the two speeds and change in error 'ce' is used as inputs for the FLC. The output of the FLC is considered as incremental change in reference armature current. The reference armature current at any instant is obtained by adding the incremental change in the previous value of reference armature current. The switching signals for chopper are obtained by comparing the actual armature current with the reference armature current and then processing the error through a hysteresis current controller [6]. The block diagram of proposed FLC is shown in fig 3.

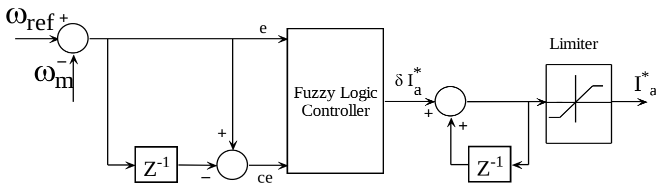


Fig.3. Block diagram of proposed FLC

In the proposed control scheme seven fuzzy levels or sets are chosen for each of the inputs and output. The seven levels are NL (negative large), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PL (positive large). The characteristics of the proposed fuzzy logic controller are as follows:

- Seven fuzzy sets for each input and output.
- Triangular membership functions for simplicity.
- Fuzzification using continuous universe of discourse.
- Implication using Mamdani's "min" operator.
- Defuzzification using the centroid method.

4.2 Design of control rules

As fuzzy logic controller (FLC) is independent of mathematical model of system, the designing of control rules is mainly based on the intuitive feeling and experience of the process. Better control performance can be obtained by using finer fuzzy partitioned subspaces (NL, NM, NS, ZE, PS, PM, PL). Where NL, NM, NS, ZE, PS, PM, and PL represent negative large, negative medium, negative small, zero, positive small, positive medium and positive large linguistic variables, respectively. The rule table with finer fuzzy partitioned subspaces for 49 rules is given as Table 1.

Table 1: Rule base for 49-rule FLC

Change in error (ce) → / Error (e)↓	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

The elements of the table are determined based on the theory that in the transient state, large errors need coarse control, which needs coarse input /output variables and in the steady state small errors need fine control, thus requires fine input / output variables. The membership functions for error (e), change of error (ce), and incremental change in reference armature current (äI^*_a) are presented in Fig. 4. The seven triangular membership functions are uniformly spaced.

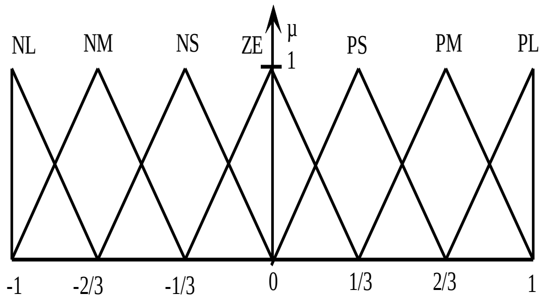


Fig.4. Membership functions for input and output variables

5. SIMULATION RESULTS

The Simulation is performed in MATLAB to establish the effectiveness of proposed FLC as a robust speed controller. The parameters of dc drive for simulation are given in Table 2 [7] and the model of proposed FLC is given in Fig. 5.

Table 2: Parameters of dc drive

Rated Power	5 HP
Rated votage	240 V
Armature resistance, Inductance	0.5 Ω, 0.01H
Field resistance	240 Ω
Field armature mutual inductance	1.23 H
Total Inertia J	0.05 kgm^2
Viscous friction coefficient B	0.02 N-ms
Hysteresis band of current controller	2 A

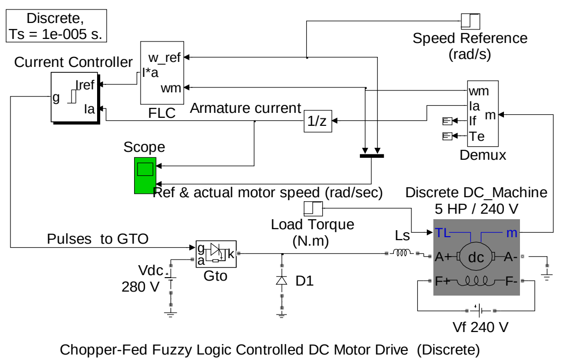
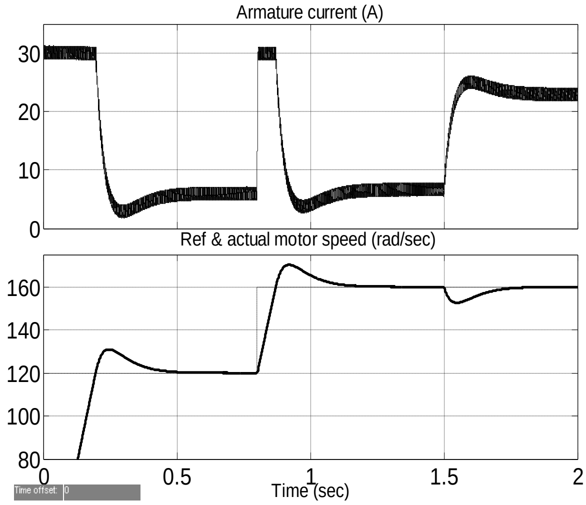
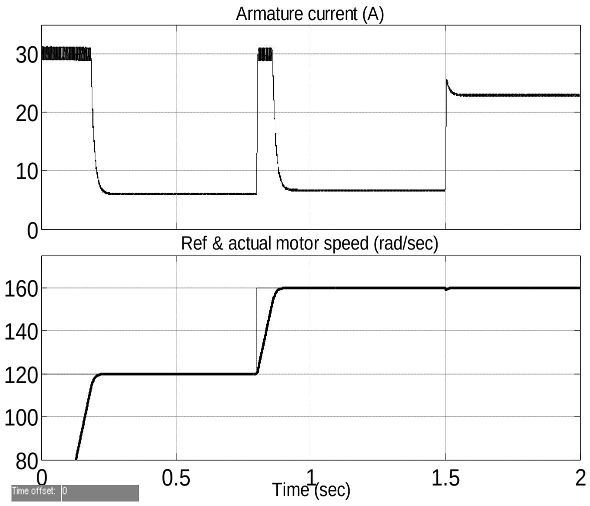


Fig.5. Simulation model of proposed FLC based chopper-fed dc drive

Initially the reference angular speed of dc motor is selected as 120 rad/sec at a load torque of 5 N-m. The speed reference signal is perturbed at 0.8 sec and given a step change of 160 rad/sec. At 1.5 sec the load torque is changed from 5 N-m to 25 N-m. The performance of dc motor drive with conventional PI controller and proposed FLC is shown in Fig. 6 (a) and (b) respectively.



(a)



(b)

Fig. 6. Dynamic response of (a) PI controller (b) proposed FLC

During switch on, the rise time of both the controllers is comparable, while the peak overshoot and settling time of PI controller is 9.1 % and 0.39 sec respectively. On the other hand there is no overshoot in case of fuzzy logic controller and settling time reduces to 0.27 sec.

When the reference speed is changed to 160 rad/sec, peak overshoot in case of PI controller becomes 6.4 % and settling time is 0.24 sec. In this case also the FLC does not show any overshoot and settling time is also much better.

During load perturbation at 1.5 sec, the load torque is increased from 5N-m to 25 N-m. The performance of FLC is in this case is also superior to conventional PI controller. The dynamic response is summarized in Table 3. The robustness of FLC is clearly evident from Table 3 in terms of improved dynamic response and less ripples in armature current.

Table 3: Comparison of dynamic response of two controllers

Response	Peak overshoot (%)		Settling Time (sec)		Peak to peak Ripples in armature current (A)	
	PI	FLC	PI	FLC	PI	FLC
Switch on response	9.1	-	0.39	0.27	2.24	0.32
Speed perturbation	6.4	-	0.24	0.08	2.29	0.35
Load Perturbation	4.6	0.56	0.15	0.06	2.30	0.35

The variation of average armature voltage depending upon reference speed and loading condition is given from Fig. 7 to 9.As soon as the reference speed is changed from 120 rad/sec to 160 rad/sec, the speed control and current control loops increases the average terminal voltage to achieve the effective control. The increase in average terminal voltage is lucidly presented by Fig. 7 and 8. Similar trend is repeated when reference load torque is increased from 5 N-m to 25 N-m as shown in Fig.9.

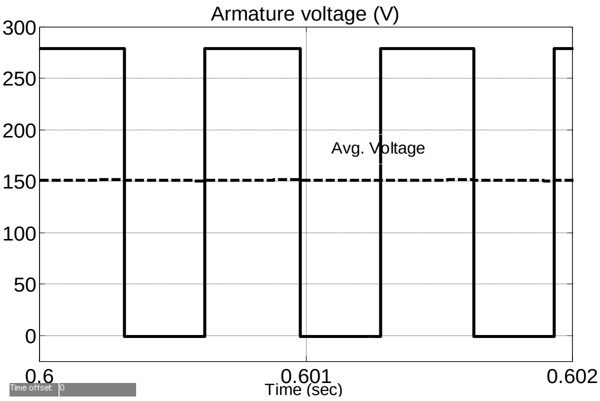


Fig.7. Waveform of armature voltage and its average value at desired speed of 120 rad/sec with load torque of 5 N-m

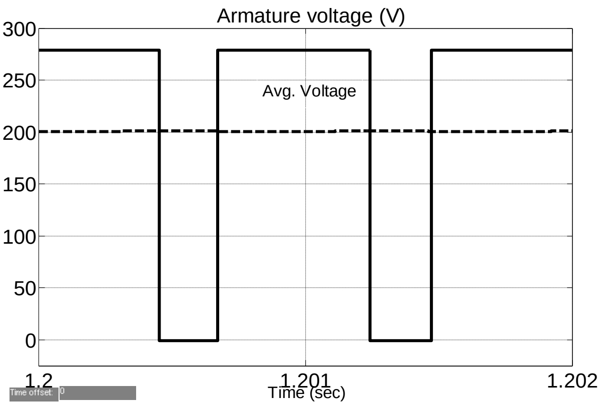


Fig.8. Waveform of armature voltage and its average value at desired speed of 160 rad/sec with load torque of 5 N-m

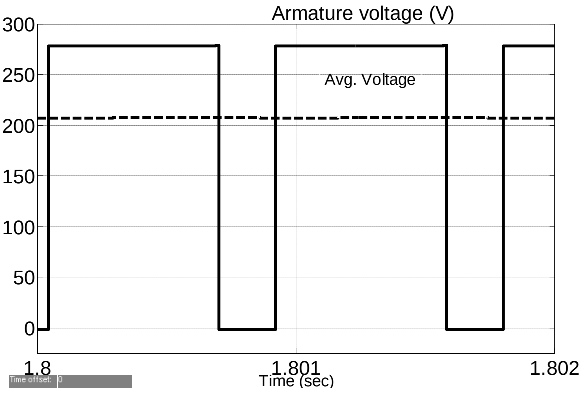


Fig. 9. Waveform of armature voltage and its average value at desired speed of 160 rad/sec with load torque of 25 N-m

6. CONCLUSIONS

The simulated closed loop performance in respect of step change in reference speed and load torque variation confirms the suitability of FLC as a better alternative of conventional PI controller. There is tremendous improvement in dynamic response of dc drive, also the peak to peak ripples in armature current have reduced considerably. The proposed FLC is less sensitive to parameter variations and hence results in more stable operation of drive. The advantages of using FLC to control dc motor are minimum overshoot in the motor speed, small settling time and limited inrush current during starting, acceleration and various loading conditions.

7. REFERENCES

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