

## Analysis of Chopper FED DC Drive System With Fuzzy Logic Speed Control

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**Abstract:** Applications of fuzzy logic to power electronics and drives are on the rise. In general the control of dc drive systems is difficult and mathematically tedious due to their high non-linearity properties. To overcome this difficulty Fuzzy Logic Control (FLC) can be developed. When compared to other intelligent control techniques like expert system and neural network, fuzzy control numerically processes structured knowledge that is embedded only in a few rules. In this paper simulation of the speed control of dc motor using FLC is described. The rules are defined for motor speed error and change in error and based on these rules, duty cycle is estimated. The efficiency of a FLC depends very much on the defuzzification process because the overall performance of the system under control is determined by the defuzzified output of the FLC. Here the most common defuzzification technique centroid method is used. In this paper the goal of designed FLC is to minimize the speed error. The controller is designed and simulated using SIMULINK toolbox of MATLAB and the performance of the driver system was evaluated. The simulation results show that the control with FLC outperforms Proportional Integral (PI) control in terms of peak overshoot, settling time, steady state error, recover time and starting torque.

**Key words:** Dc Motor • Fuzzy Logic • Speed Control • Defuzzification • MATLAB/SIMULINK

### INTRODUCTION

The speed of DC motors can be adjusted within wide boundaries so that this provides easy controllability and high performance. DC motors used in many applications such as still rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators require speed controllers to perform their tasks. Speed controller of DC motors is carried out by means of voltage control in 1981 firstly by Ward Leonard [1]. The regulated voltage sources used for DC motor speed control have gained more importance after the introduction of thyristor as switching devices in power electronics. Then semiconductor components such as MOSFET, IGBT and GTO have been used as electric switching devices [2].

In general, the control of systems is difficult and mathematically tedious due to their high nonlinearity properties. To overcome this difficulty, FLC can be developed. The best applications of FLC are the time variant systems that are nonlinear and ill-defined [3].

Nowadays, FLC applications are successfully used in many fields including automatic focus cameras, household materials such as dishwashers, automobile industry etc.

In this study, the speed response of a DC motor exposed to fixed armature voltage was investigated for different load conditions [4]. At first, the DC motor was operated for a required reference speed under loaded and unloaded operating conditions using PI control method. Then, to make performance comparison, the speed of the system was controlled using FLC. The FLC system designed for operating at fixed speed under different load conditions are simulated at MATLAB/Simulink environment

### System Description

**Pi Controller Description and Design:** A separately excited DC motor is considered to be a multi-input, multi-output system. This machine is widely used in many variable speed drives. Open-loop operation of the motor can be unsatisfactory in some industrial applications.

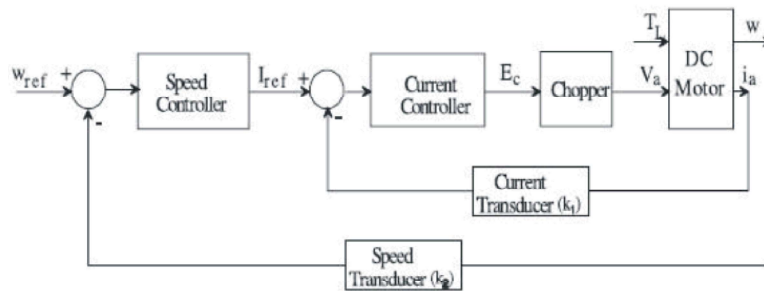


Fig. 1: PI controlled chopper fed dc drive system

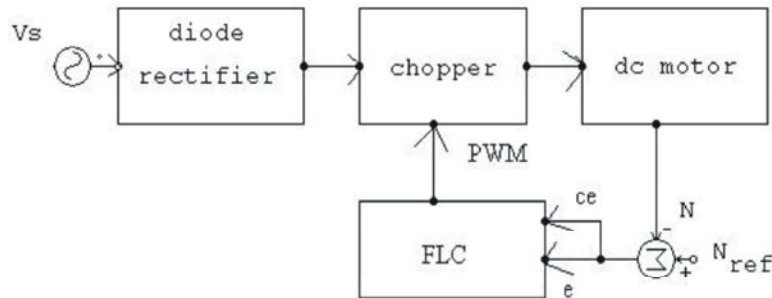


Fig. 2: Fuzzy controlled chopper fed dc drive system

If the drive requires constant-speed operation under changing load torque, closed-loop control is necessary. The closed-loop speed control system in this study consists of a separately excited DC motor, a class E Pulse Width Modulated (PWM) chopper and PI speed and current controllers. The block diagram representation of the system is given in Fig. 1. The closed-loop control of the motor has basically two feedback loops. The outer loop is a speed feedback loop and the inner loop is the current feedback loop. The controllers used in these loops are both of PI type. The speed controller output is the reference for the current controller. The output of the current controller is the input to the PWM generator that controls the motor input voltage [5-7].

**Fuzzy Logic Controller Description and Design:** The fuzzy logic foundation is based on the simulation of people's opinions and perceptions to control any system. One of the methods to simplify complex systems is to tolerate to imprecision, vagueness and uncertainty up to some extent [3]. An expert operator develops flexible control mechanism using words like "suitable, not very suitable, high, little high much and far too much" that are frequently used words in people's life. Fuzzy logic control is constructed on these logical relationships. Fuzzy sets are used to show linguistic variables. Fuzzy Sets Theory is first introduced in 1965 by Zadeh to express and process fuzzy knowledge. There is a strong relationship

between fuzzy logic and fuzzy set theory that is similar relationship between Boolean logic and classic set theory. Fig. 2 shows a basic FLC control of dc motor [8-11].

Although the classic controllers depend on the accuracy of the system model and parameters, FLC uses different strategies for motor speed control. Basically, FLC process is based on experiences and linguistic definitions instead of system model. It is not required to know exact system model to design FLC. In addition to this, if there is not enough knowledge about control process, FLC may not give satisfactory results [3].

#### Defining Inputs, Outputs and Universe of Discourse:

The goal of designed FLC in this study is to minimize speed error. The bigger speed error the bigger controller input is expected. In addition, the change of error plays an important role to define controller input. Consequently FLC uses error ( $e$ ) and change of error ( $\dot{e}$ ) for linguistic variables which are generated from the control rules. Equation (1) determines required system equations. The output variable is the change in control variable ( $\ddot{e}$ ) of motor driver.  $\ddot{e}$  is integrated to achieve desired alpha value. Here  $\alpha$  is an angular value determining duty cycle of DC-DC converter designed in this paper [12-15].

**Defining Membership Functions and Rules:** System speed comes to reference value by means of the defined rules. For example, first rule on Table 2 determines, if ( $e$ ) is

Table 1: Rule for PD like and PI like FLC

e/e	NL	NM	NS	Z	PS	PM	PL	e/e	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	PM	PS	Z	NL	PL	PL	PL	PL	NM	Z	Z
NM	PL	PL	PL	PM	PS	Z	NS	NM	PL	PL	PL	PM	PS	Z	Z
NS	PL	PL	PM	PS	Z	NS	NM	NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL	Z	PL	PM	PS	Z	NS	NM	NL
PS	PM	PS	Z	NS	NM	NL	NL	PS	Z	Z	NM	NS	NS	NM	NL
PM	PS	Z	NS	NM	NL	NL	NL	PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	NS	NM	NL	NL	NL	NL	PL	Z	Z	NM	NL	NL	NL	NL

Table 2: performance parameter for PI and fuzzy logic controller

Controller	At start up				Torque load change at 500 m-sec		
	$M_p$ in %	$T_s$ (msec)	$T_{ep}$ (NM)	Ess	$M_p$ in %	$T_{rec}$ (msec)	Ess
PI controller	26	390	118	1.2	20.8	1220	0.8
Fuzzy logic controller	1.8	88	64	0.02	11.1	554	0.02

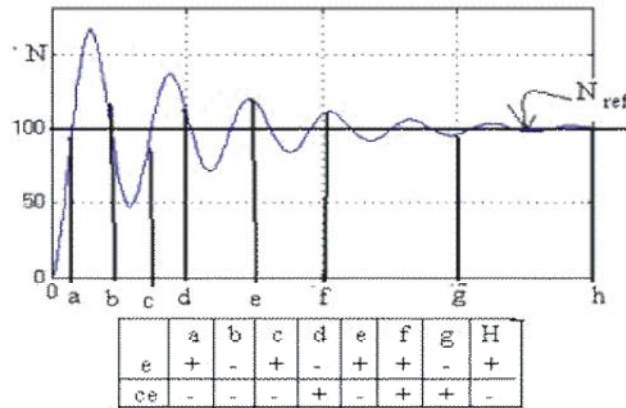


Fig. 3: Dynamic signal analysis

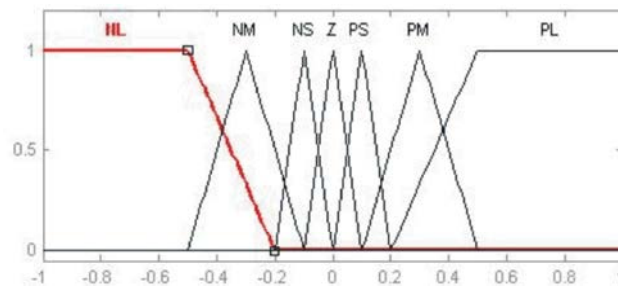


Fig. 4: Membership function for input and output

NL and (•e) is NL than (••) is PL. According to this rule, if error value is negative large and change of error value is negative large than output, change of alpha will be positive large. In this condition, corresponding b interval in Fig. 3, motor speed is larger than reference speed and still wants to increase strongly. This is one of the worst conditions in control process. Because of the fact that alpha is smaller than the required value, its value can be increased by giving output PL value [16-18]. This state corresponds to motor voltage decreasing. All conditions in control process are shown in Fig. 3.

To calculate the FLC output value, the inputs and outputs must be converted from crisp value into linguistic form. Fuzzy membership functions are used to perform this conversion. In this paper, all membership functions are defined between -1 and 1 interval by means of input scaling factors  $K1_E$ ,  $K2_{•E}$  and output scaling factor  $K3_{••}$ . Since simple numbers are now processed in controller after scaling, fuzzy computation is performed in a shorter time. The linguistic terms for input and output values are represented by seven membership functions as shown in Fig. 4.

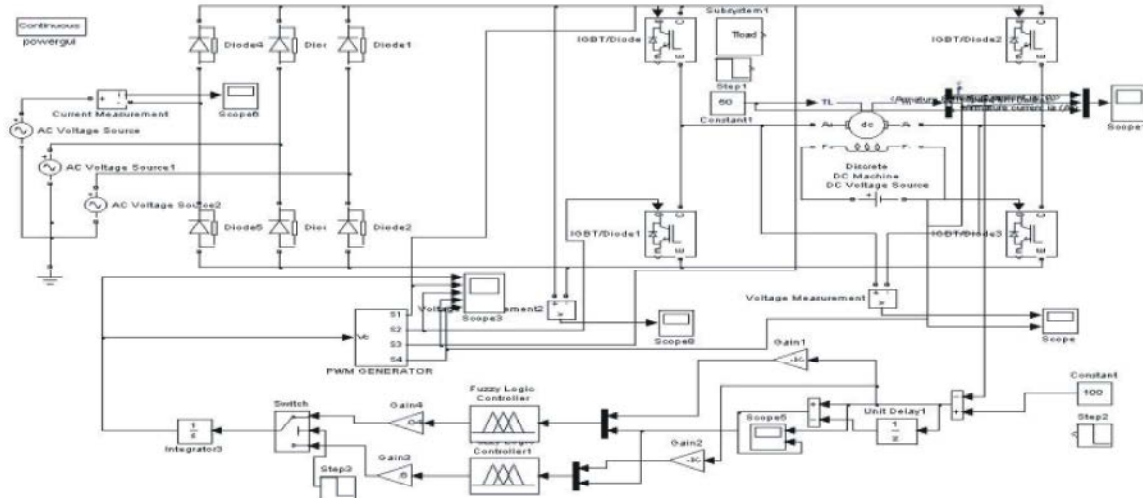


Fig. 6: Simulink model for FLC control of DC motor

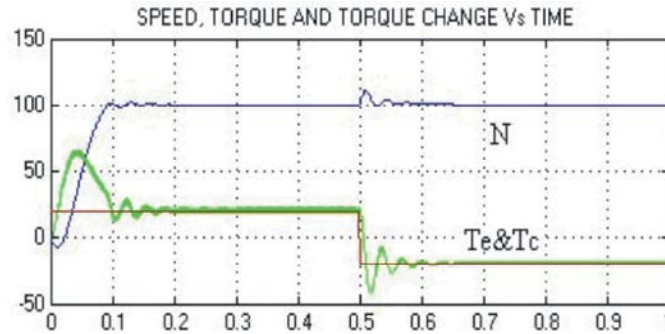


Fig. 7: Simulation result for FLC control of DC motor

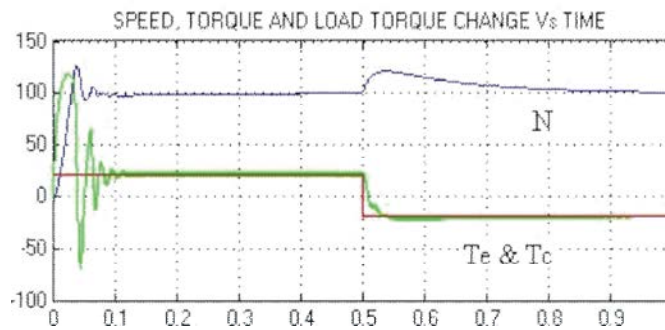


Fig. 8: Simulation result for PI control of DC motor

### Simulation

**Driver Circuit and Modeling:** DC choppers used as a driver in this work change the average value of load voltage applied from a three phase diode rectifier by switching a power switch such as IGBT or MOSFET. With wide usage ranges in power electronics, separately excited and serial DC motor speed control can be mentioned as the most important application area of DC choppers. The average output voltage can be calculated as,

$$V_o = \frac{t_{on}}{t_{off} + t_{on}} V_{dc} \quad (2)$$

where  $V_{dc}$  is the DC source voltage.  $V_o$  can be controlled using three methods,

- Hold  $t_{off}$  fixed and change  $t_{on}$  (frequency modulation)
- Hold period ( $t_{off} + t_{on}$ ) fixed and change  $t_{on}/t_{off}$  rate (PWM)
- Combination of first and second method

In this paper, four-quadrant DC chopper is designed as a driver. In four-quadrant driver, load voltage and load current can take positive or negative values.

Fundamentally, the operating principle of driver model is based on the comparison of two signals [4]. One of the signals is a triangular waveform which represents one period of 600 Hz chopping frequency and other one is fixed linear signal which represents time equivalent of alpha triggering angle  $t_\alpha$ .

Simulink model of fuzzy logic speed control of DC motor is shown in Fig. 6. Reference speed is defined as 100 rad/s. Gain 1, Gain 2 and Gain 3 in the model, define change of error, error and change of alpha scaling factors, respectively. 20 Nm load is applied to motor at 0 sec and -20 Nm load is applied to motor at 0.5 sec. Simulation results are shown in Fig. 7. Simulation result for PI controlled chopper fed dc drive system is shown in Fig. 8.

The controller is simulated for different loading conditions, then settling time ( $T_s$ ), steady state error ( $E_{ss}$ ), percent peak over shoot ( $M_p\%$ ), recover time ( $T_{rec}$ ) and starting torque ( $T_{sp}$ ) have been measured. PI controller response and FLC response are compared in Table 2. As seen from the table, FLC outperforms PI controller in terms of settling time, steady state error, percent peak over shoot, recover time and reducing starting torque criteria.

## CONCLUSION

Separately excited dc motor speed control has been performed in MATLAB simulink environment. Dc motor speed has been controlled with classical PI controller and variable structure fuzzy logic controller. Simulation results shows that variable structure FLC has clearly better performance for providing settling time ( $T_s$ ), steady state error ( $E_{ss}$ ), percent peak over shoot ( $M_p\%$ ), recover time ( $T_{rec}$ ) and reducing starting torque ( $T_{sp}$ ) criteria in comparison with PI controller. FLC also has more sensitive response against load disturbance in according to classical PI controller. It would be possible to get better PI controller performances by increasing  $K_p$  and  $K_i$  coefficient. But in case, it will be a problem in real application of PI controller.

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