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Comparative Study between Conventional PID and Fuzzy Logic Controller for a Current Controlled D.C. Drive Using MATLAB/Simulink

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ABSTRACT: This paper describes a closed loop model of a current controlled PMDC motor drive with two controller FUZZY & PID separately, then comparison of the effect on output parameters for this two different controller is established. The differences between the output speed of PMDC motor & a preset reference speed is fed as an error signal to the controller of the system. The output of the speed controller (actuating signal) controls the duty cycle of converter and hence controls the converter output. Through this controlled converter output, required voltage gets injected into the motor. A small change in the injected voltage can cause a large change in the motor current and hence leading to a particular drive control feature. In the past few years Fuzzy Logic became a very much popular choice of controller for feedback control of various industrial systems. Fuzzy logic control is much closer in spirit to human thinking and logical reasoning than conventional controller like PID or PI. Recent study shows that this type of controller (FUZZY) provides better settling time, low peak overshoot and less percent of steady state error in overall system output which leads to better stability of overall system. In this Paper, a performance analysis of the conventional PID controller and fuzzy logic controller has been done by the use of MATLAB.

KEYWORDS: Permanent Magnet DC motor, DC-DC Step-down Chopper, Closed Loop Control, Proportional-Integral-Derivation controller, Fuzzy Controller.

I. RELATED WORK

PM motor drives have been a topic of interest for the last twenty years. Different authors have carried out modelling and simulation of such drives. The three most common speed control methods of a dc motor are field resistance control, armature voltage control, and armature resistance control [1][2].

Depending on the armature voltage control method simulink model of a current mode buck-type dc chopper-fed permanent-magnet (PM) dc motor drive with proportional controller in its feedback loop is realized [3][4]. But the importance of PID controllers in process industry cannot be overemphasized because although some modern controllers like FUZZY got popularity, the majority of the industrial controllers use PID or modified PID control schemes [5].

Investigate through both numerically and through simulink model, the characteristics of different electrical parameters [current, speed, different torques working etc] of current mode buck-type dc chopper-fed permanent-magnet (PM) dc motor with PID controller in its feedback loop is also done [6][7].

Fuzzy control is proposed as one of the most active and fruitful areas of research especially in industrial processes. Fuzzy control is based on fuzzy logic, a logical system which is much closer to human thinking and natural language than traditional logical systems [8]. It is also shown that, fuzzy logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzification, defuzzification strategies and fuzzy control rules are used in fuzzy reasoning mechanism [9].

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II. INTRODUCTION

Developments of high performance motor drives are very essential for industrial applications. A high performance motor drive system must have good dynamic speed command tracking and load regulating response. DC motors provide excellent control of speed for acceleration and deceleration and chopper fed permanent magnet PMDC motor allows precise voltage control, which is necessary for speed and torque control applications.

DC drives, because of their simplicity, ease of application, reliability and favourable cost have long been a backbone of industrial applications. DC drives are less complex as compared to AC drives system. DC drives are normally less expensive for low horsepower ratings.

PMDC motors are conveniently portable and well fit to special applications, like industrial equipments and machineries that are not easily run from remote power sources. PMDC motor is considered a SISO (Single Input and Single Output) system having torque/speed characteristics compatible with most mechanical loads. This makes a PMDC motor controllable over a wide range of speeds by proper adjustment of the terminal voltage using various innovative design and control techniques [2].

In case of this project a DC-DC Step-down Chopper is used to adjust the terminal voltage as per requirement .This is done by controlling switch of the chopper through a closed loop control. As in process industry importance of PID (proportional-integral-derivative) controllers cannot be overemphasized because although some modern controller like FUZZY got popularity, the majority of the industrial controllers use PID or modified PID control schemes [10].

Fuzzy control has emerged as one of the most active and fruitful areas of research especially in industrial processes [8]. Fuzzy logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzification, defuzzification strategies and fuzzy control rules are used in fuzzy reasoning mechanism[9]. Fuzzy logic control has been successfully used in various application areas ranging from automatic train operation to flight systems. Fuzzy logic enables control engineers to efficiently develop control strategies in application areas marked by low order dynamics with weak non linearities.

Hence, the effect of a conventional [PID] controller on a practical DC Drive is compared & analysed in this paper with the same drive using fuzzy controller instead of conventional controller in its feedback path.

III. PROJECT OVERVIEW

The basic principle which has been adopted for the speed control of this modelled DC drive is variation of armature voltage for speed below and up to rated speed with field voltage constant because of using permanent magnet dc motor where field is produced by permanent magnets. There are two control loops, one for controlling current and another for speed [6]. The output speed has been compared with the reference speed and error signal is fed to speed controller [5]. Now whenever a deviation of motor speed from provided reference speed occurs, controller output will vary as well. This controller output signal termed as speed control signal $y(t)$ will control the voltage fed to the motor by controlling the duty cycle of the convert (step down chopper) [12]. As a result, required amount of input voltage [V_{in}] will be injected to the motor [13][14].

A simple block diagram representation of proposed design is shown below:

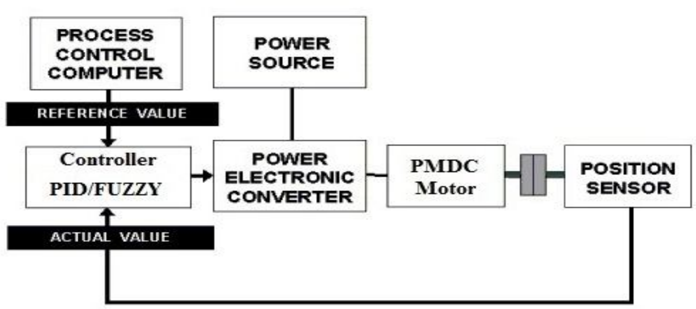

Fig.1 Block diagram of proposed system

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As shown in the simplified block diagram, as controller a conventional controller like P,PI or PID can be used, but Proportional integrated Derivative (PID) controllers are widely used in process control applications, but they exhibit the poor performance when applied to systems, which are nonlinear, as controller tuning is difficult due to insufficient knowledge of the parameters of the system. The proposed system in this paper is a typical example. Fuzzy controller gave a better performance compared to the PID controller. It gives better performance with reduced oscillations and faster settling time. Hence, Fuzzy logic and proportional-integral-derivative (PID) controllers are compared for proposed DC drive. A simulation study of the PID controller in comparison with fuzzy logic controller for the armature voltage control method with fixed field for designed DC drive performed.

IV. MODELLING OF PROPOSED DC DRIVE SYSTEM WITH PID CONTROLLER

As discussed till now the best way to design a dc drive with speed control option is by using a DC-DC step down converter to feed the PMDC motor. Speed control will be achieved by controlling the duty cycle of the power electronics device [GTO] used as switch. For regulation of the duty cycle, the control or error signal can be produced by comparing the motor output speed with the reference speed and this generated error signal is fed to PID [speed] controller. Controller output will vary whenever there is a difference in the reference speed and the actual motor speed. The output of the PID [speed] controller or the actuating signal so generated will control the duty cycle of converter. Now the converter output will give the required V_{in} required to bring motor back to the desired speed [15].

The corresponding equivalent circuit is shown in Fig. 3 which will be used throughout the analysis:

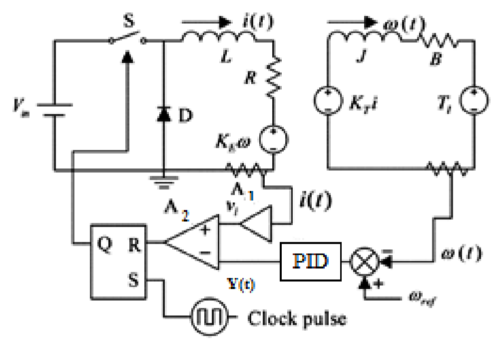

Fig. 2 Equivalent circuit Current-controlled DC drive system

Let us assume that operational amplifier **A_1**, have gains g_i , the current control signal V_i and speed control signal [in our case output of the PID controller] y(t) can be expressed as:

$$y(t) = k_p(\omega_{ref} - \omega) + \frac{k_p}{T_i}\int(\omega_{ref} - \omega) + k_d\frac{d}{dt}(\omega_{ref} - \omega) \quad (1)$$

$$V_i(t) = g_i\, i(t) \quad (2)$$

Here,
$i(t)$= armature current of the dc motor, $\omega(t)$ = speed of the dc motor, ω_{ref} = reference speed of the dc motor.

From Fig. 2 it can be see that both $y(t)$ and $V_i(t)$ are inserted into the comparator A_2 and this comparator outputs the pulse to the reset of an R-S latch. This R-S latch controls the switch S of the dc-dc step down converter and a clock pulses of period T sets the R-S latch. Once the clock pulse sets the latch, switch S is "ON" and the diode is "OFF". From this instance the switch S will be in "ON" until y(t) exceeds $V_i(t)$ and at that point of time the latch will begins to reset. After this reset S is turned off and D is on. Here on S remains open until the arrival of the next clock pulse where it will be closed again. If both set and reset signals occur at the same time, the reset will dominate the set so that S keeps open until the occurrence of another clock pulse. Therefore, the system equation can be divided into two stages as given by [15] -

STATE EQUIATION IS GIVEN BELOW:

A. STAGE 1:

When $V_\omega > V_i$ means switch "S" is in ON state

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$$\frac{di}{dt} = \frac{1}{L}(V_{in} - Ri_a - K_E\,\omega) \tag{3}$$
$$\frac{d\omega}{dt} = \frac{1}{J}(K_T\,i_a - B_{\,\omega} - T_L) \tag{4}$$
$$\frac{dy(t)}{dt} = -K_p\frac{d\omega}{dt} + \frac{K_p}{T_i}(\omega_{ref} - \omega) + K_D\frac{B}{J} \tag{5}$$

B. STAGE 2:

When $V_i > V\omega$ means switch "S" is OFF state.

$$\frac{di}{dt} = \frac{1}{L}(-Ri_a - K_E\,\omega) \tag{6}$$
$$\frac{d\omega}{dt} = \frac{1}{J}(K_T\,i_a - B\,\omega - T_L) \tag{7}$$
$$\frac{dy(t)}{dt} = -K_p\frac{d\omega}{dt} + \frac{K_p}{T_i}(\omega_{ref} - \omega) + K_D\frac{B}{J} \tag{8}$$

Where R is armature resistance, L is armature inductance, V_{in} is dc supply voltage, K_E is back-EMF constant, K_T is torque constant, B is viscous damping, J is load inertia, & T_L is load torque.

V. MODELLING OF PROPOSED SYSTEM WITH FUZZY CONTROLLER

The Fuzzy Logic tool was introduced by Lotfi Zadeh (1965), and is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership the important concept of computing with words. It provides a technique to deal with imprecision. The fuzzy theory provides a mechanism for representing linguistic constructs such as "many," "low," "medium," "often," "few." In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. Fuzzy logic systems are suitable for approximate reasoning. Fuzzy logic systems have faster and smoother response than conventional systems and control complexity is less. The basic building block diagram of a Fuzzy system is given below[8].

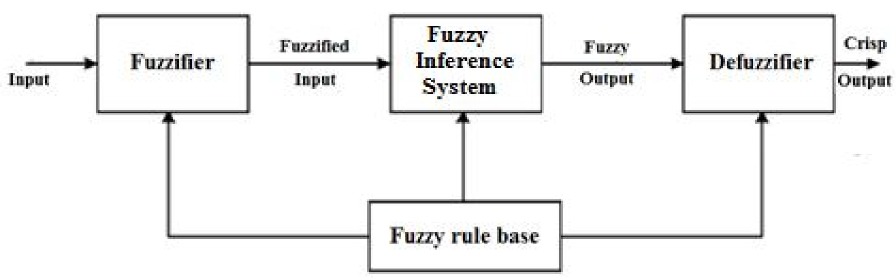

Fig. 2 A Simple Fuzzy System

A simple fuzzy system consists of four blocks: A Fuzzifier, Defuzzifier, inference engine and fuzzy rule knowledge base. Fuzzy Logic Controller (FLC) is an attractive choice when precise mathematical formulations are not possible. Other advantages are:

- ✓ It can work with less precise inputs.
- ✓ It doesn't need fast processors.
- ✓ It is more robust than other non-linear controllers.

The proposed Fuzzy controller will be a PID-like controller having two inputs, error(E) and change of error(DE) and one output reference current (I_r). Deciding on the no of membership functions, there are two counter Interest: (1) the rule base is proportional to the number of membership functions, thus in order to keep the evaluation time low the number of membership functions are set as low as possible; (2) on the other hand the number of membership functions determines the smoothness of the fuzzy controller response, hence we would like to set it as high as possible.

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A schematic model of the FLC is shown in Fig. 3

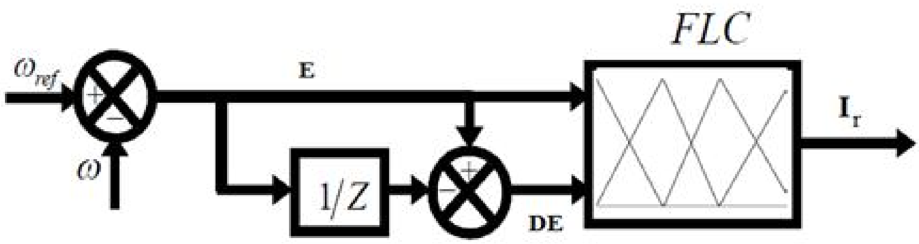

Fig. 3 Schematic model of fuzzy logic controller

Let's start from the lower number of number of membership function. There is no reason of choosing only one membership function per input, thus having only one rule. Choosing two membership functions we have a conflict built in the fuzzy controller. In case of steady-state, that is the error and change of error is near to zero, all the rules are firing at the same level, thus the defuzzyfication process have to resolve the conflict between the contradictory fuzzy sets suggested by the rules. In conclusion three membership functions must be chosen for the inputs. But to achieve higher degree of smoothness of the fuzzy controller response and higher accuracy at the overall system response, in this paper five number of membership functions are chosen[8].

Here in this FLC, a rule base is defined to control the output variable. This fuzzy rule is a simple IF-THEN rule with some condition and conclusion which relates the input variables to the required output variables properties. The FLC converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by an expert knowledge and human experience with understanding. Initially, the speed error 'E' and the rate of change in speed error 'DE' have been placed as input variables of the FLC. Then the output variable of the FLC generates output reference current (I_r). The fuzzy rules are expressed in English like language with syntax such as, **If** {error speed 'E' is X and rate of change of error speed 'DE' is Y} **then** {control output variable I_r is Z}. To convert these numerical variables into linguistic variables, as discussed before five fuzzy levels or sets (membership functions) has been chosen as: NB (Negative big), NS (Negative small), ZE (Zero), PS (Positive small), and PB (positive big) are used and summarized in Table 1. Each of the inputs and the output contain membership functions with all these three linguistics with 5*5 Triangular MFs[9].

TABLE I
FUZZY LOGIC CONTROL RULES

DE \ E	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

The mapping of the fuzzy inputs into the required output is derived with the help of a rule base as given in Table I. Each rule of the FLC is defined with an **If** part called the antecedent, and with a **then** part called the subsequent. The antecedent of a rule contains a set of conditions and the subsequent contains a set of conclusions. So "If the conditions of the antecedents are satisfied, then the conclusions of the subsequent will be applied". Finally the output consequences will be fuzzy in nature and has to be converted into a crisp value by using any Defuzzification technique.

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Vol. 3, Issue 4, April 2014

VI. MATLAB SIMULATION RESULTS

As discussed up to this point, the last objective is to model and simulate [1] a buck chopper fed PMDC motor with a PID controller oriented feedback loop through MATLAB software [3][16] and then use a Fuzzy controller instead of conventional PID Controller in the feedback loop of the system and compare the output motor speed response of later with former. This objective is fulfilled with following parameter values:

TABLE III
PARAMETER VALUES OF MODELLED DC DRIVE

Various Machine Parameters	**Parameter Values**
Viscous damping [B]	0.000564 Nm/rad/s
Load inertia [J]	0.000971 Nms^2
Back-EMF constant [K_E]	0.1356 V/rad/s
Torque constant [K_T]	0.1324Nm/A
Armature Resistance [R_a]	3.5 Ω
Armature Inductance [L_a]	36 mH
Input voltage [V_{in}]	100 V
Reference speed [ω_{ref}]	100 r.p.m
Load torque [T_{load}]	0.27Nm

Time Plot of speed for PID controller

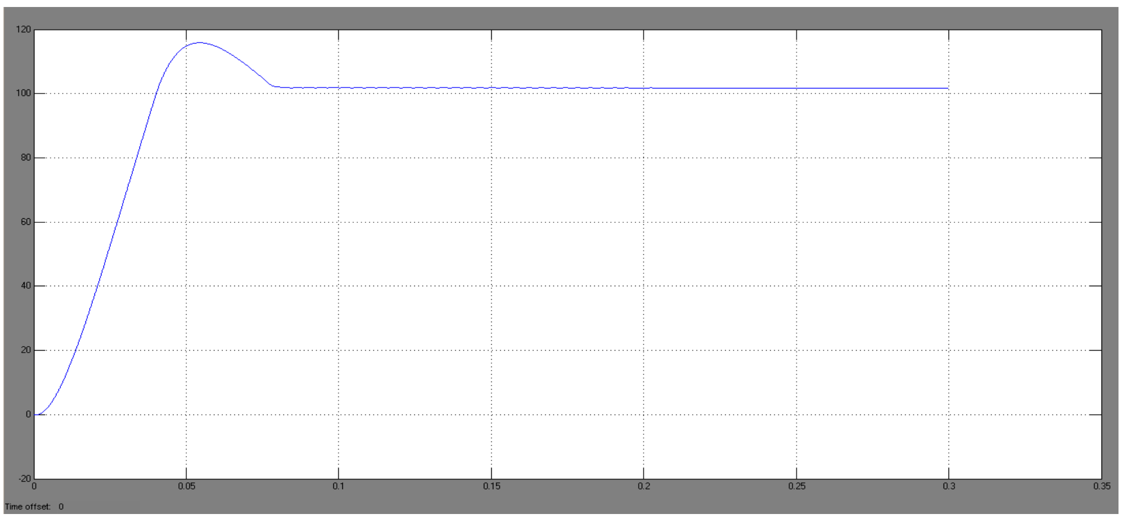

Fig.3 Time plot of motor speed.

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Time Plot of speed for FUZZY controller

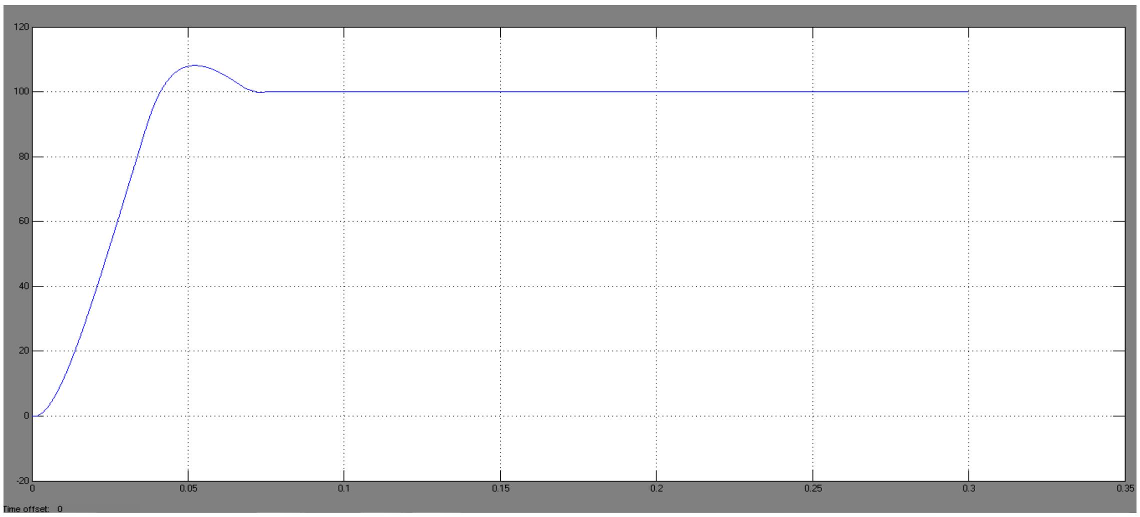

Fig 4. Time plot of motor armature speed.

TABLE III
COMPARING VARIOUS TIME DOMAIN SPECIFICATIONS

Time Domain Specifications	**Controller Used**	**Delay Time(Td) in sec**	**Rise Time(Tr) in sec**	**Settling Time(Ts) in sec**	**Peak Overshoot(Mp) in %**	**%Steady State Error(Ess)**
Motor Speed	PID Controller	.0242	.04	.082	15.9	1.6
	FUZZY Logic Controller	.024	.04	.066	8.1	0

From these results it can be seen that Fuzzy controllers have better stability, small overshoot, fast response and lower steady state error.

VII. CONCLUSION

Overall the project's feasibility lies in the simplicity of its implementation. The advantages of a system with fuzzy controller over a conventional controller like, PID controller are derived from results. As described earlier, from the fuzzy controller based system better control performance, overall stability and robustness can be expected. From the results derived in this paper the following points can be observed, that fuzzy controllers have better stability, small overshoot, fast response and lower steady state error.

The performance assessment of the studied position controllers is based on transient response and error integral criteria. The results obtained from the fuzzy logic controller are not only superior in the rise time, speed fluctuations, and percent overshoot but also much better in the controller output signal structure, which is much remarkable in terms of the hardware implementation. Hence, it is concluded that introduction of fuzzy logic controller over conventional PID controller for speed control of a current control DC drive is further beneficial.

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