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A Comparative Study on Different Speed Control Methods of D.C. Drives for Electric Vehicle

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Abstract:
This paper describes a comparison of closed loop speed control of a separately excited DC motor using IGBT Chopper with the help of Fuzzy logic controller (FLC) and MATLAB / Simulink. In many industrial applications, conversion of constant voltage DC source into a variable voltage or variable current for the speed control of DC motor is required. For such type of operation a converter is used known as chopper. This paper explains the development of PI controller and a fuzzy tuned PI controller for speed control of DC motor. The simulation results are presented and analyzed in this paper.

Keywords: Fuzzy Logic Control (FLC); MATLAB/Simulink; DC motor; Power IGBT; closed loop operation

Introduction:
Many researches are done in designing high performance motor drives as industries are demanding more robust and high performance drives. A drive should maintain dynamic speed response. Among all the motors DC motor provides excellent control of speed for acceleration. Main advantage of using DC motor in drive application is that the power supply is directly fed to field of motor which allows a precision voltage control which is useful in speed and torque control application [1]. Although AC motor are mainly used in industry but DC motor are still used in several applications such as electric vehicle (EV) propulsion, textile industries and in public transport TRAM(trolley) and metro. The control of DC motor is usually made of power electronic devices. DC motor drive is classified according to the type of the converter which is utilized in order to control the speed and torque of the DC motor. When a DC to DC converter is used the motor is called chopper fed DC motor drive.[14] DC drives are widely used in industrial applications. It is considered as single input and single output system having speed torque characteristics well suited with most mechanical loads. Controlled rectifier provides a variable dc voltage from a fixed dc voltage. Due to their ability to supply a continuously variable dc voltage, controlled rectifier and dc chopper made a revolution in modern industrial equipment and variable speed drives.[6]Chopper is a static power electronic device that converts fixed DC input voltage to variable DC output voltage. Chopper systems are characterized by high efficiency, and fast response. Choppers are now being used all over the world for rapid transit system. It has replaced controlled rectifier converter in many applications due to high efficiency, fast response.[18]

Speed Control of DC Motor: Conventional DC motors have a field circuit and an armature. There are three different operating characteristics in the method of field connection, the separately excited machine, the shunt motor and the series motor. The direct current motor is usually fed from an adjustable supply [12].In this paper a direct current motor is fed by a chopper. Speed control of DC motor, namely field resistance control, armature voltage control, armature resistance control methods. The armature voltage control method is used commonly to control the speed of DC motor.[4] DC motors are fed from a power electronic converter such as a chopper and therefore a nonlinear torque speed characteristics might be observed in the motor performance.

Equation for speed of DC motor is given as:

$$\omega m = \frac{Vt - IaRa}{K\varphi} \quad \text{…………(1)}$$

The description for the notations used is as follows:

a) $V_t$is the armature terminal voltage in volts.
b) Ia is the armature current in amperes.
c) Ra is the armature resistance in ohms.
d) ɸis the flux in webers.
e) K is the constant.

This shows that the speed of DC motor can be varied by controlling the field flux, armature resistance and the armature terminal voltage. Therefore there are three speed control methods namely the filed flux control, armature resistance control, armature voltage control.[2]This paper presents a Simulink model for closed loop speed control method where speed is controlled by armature terminal voltage method by a using IGBT chopper. In the armature terminal voltage method the voltage applied to the armature terminal is varied. The armature terminal voltage V_t is varied without making any change in the applied voltage of the motor. By the armature terminal voltage, only speed below the base speed can be controlled. In order to achieve a speed above the base speed, an excessive armature voltage is required which can also damage the armature circuit.[15]

Electric Vehicles: A separately excited dc motor propulsion system provides several improvements in system performance while at the same time can retain the advantage ofthe series motor. The speed of the motor can be increased by a ratio at least 2: 1 over the base speed by field weakening control which permits higher gear ratio for a given motor. Since the field current is smooth, the motor pulsating torque is less, and the reflected battery current is smoother when the current is controlled by a high-frequency chopper [8].Many dc-dc converters are recently adopted in automotive applications, particularly in electric vehicles (EVs), hybrid electric vehicles (HEVs), fuel cell vehicles. Recently, unfavorable Earth Environment due to exhaust gas from cars becomes more serious.Variable voltage system is presented to solve such problem by using a buck-boost chopper. [11]

Controllers: The term controller is defined as a device which when introduced in feedback or the forward path of a system.A control system should meet the specifications regarding its performance and the system performance can be improved by using control methods. The control methods are as follows:

i) Proportional control.
ii) Proportional derivative control.
iii) Proportional integral control.
iv) Proportional integral derivative control.[17]

PI Controller: The proportional integral controller is a controller which produces a signal proportional to the error signal added to the integral of the error signal. The proportional plus integral controller increases the order of system by one resulting in reduction of steady state error.[13].It can be represented by equation-

$$m(t) = K_p.e(t) + K_p.K_i \int_0^t e(t)dt$$

$$m(t) = K_p.e(t) + K_p.\frac{1}{T_i} \int_0^t e(t)dt \quad \text{…………(2)}$$

Taking Laplace Transform of equation 2

$$M(s) = K_p.E(s) + \frac{K_p}{sT_i}.E(s) = E(s)[1+\frac{1}{sT_i}]K_p$$

$$\frac{M(s)}{E(s)} = [1+\frac{1}{sT_i}]K_p .$$

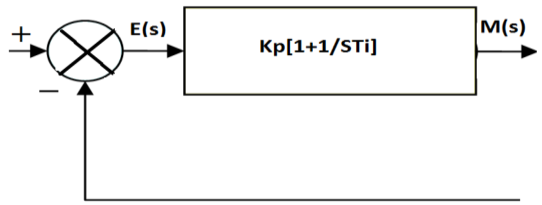


Fig.1. Block Diagram of PI controller

Fuzzy Logic Control*:*Fuzzy PI control is the PI control based on fuzzy control theory, The fuzzy theory is to solve life common fuzzy phenomena.Fuzzy control is the modern emerging a control that is the outcome of the combination with the fuzzy theory, and automatic control technology. Fuzzy reasoning method uses Mamdani reasoning algorithm. Mamdani reasoning algorithm based on modified Zadeh reasoning algorithm.[5]

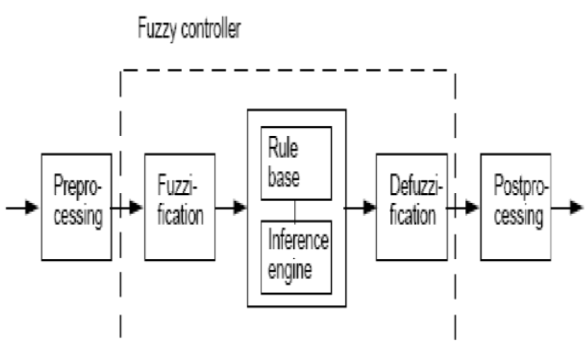


Fig.2.Fuzzy logic controller

The traditional PI algorithm for nonlinear time-varying control system is not easy to adjust the control parameters and the fuzzy control theory with its powerful ability and processing power to better solve such problem.[7] The traditional PI control is through the regulation PI control parameters to achieve the stability of the system,and the fuzzy PI can set the PI parameters online. Establish the rules of the fuzzy control table will connect the error signal e, therate of change of error signal de and the two PI parameters.[16]

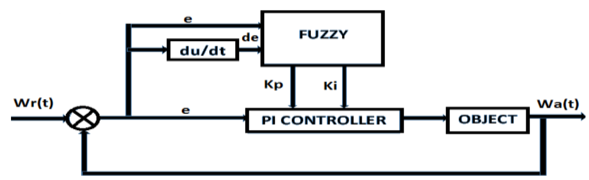


Fig.3.Theself-tuningfuzzyPIcontroller

Simulation and Results: This paper presents a MATLAB/Simulink model of IGBT chopper based speed control method and analysis of chopper fed dc motor. A 5HP DC motor of 240V rating 1750 rpm with field voltage of 300V is used in the model. The specification of the DC motor used as follows:

Table.1.Specification of model of DC motor

S.No	*Parameters*	*Value*
1	DC motor rating	5HP
2	DC input voltage	240V
3	DC field voltage	300V
4	Rated speed	1750 Rpm
5	Armature resistance(Ra)	2.581Ω
6	Armature inductance(La)	0.028H
7	Field resistance(Rf)	281.3Ω
8	Field inductance(Lf)	156H
9	Total inertia(J)	0.02215Kg.m^2
10	Viscous friction coefficient(Bm)	0.002953N.m.s
11	Coulomb friction torque(Tf)	0.5161N.m

In the Simulink model of DC motor the armature circuit is fed from a IGBT chopper and a freewheeling diode is also used to solve the stored inductive energy in the circuit. The field circuit is separately excited from a separate DC source of 240 volts. [3]An access is provided to the field connections (F+, F-) so that the motor can be used as a shunt connected.The field circuit is represented by an RL circuit (R_f and L_f in series) and is connected between the ports (F+ , F-) The armature circuit consists of an inductor L_a and resistor R_a in series with an electromotive force E_A and is connected between the ports (A+ , A-).[10]The load torque is specified by the input port T_L . The output port m allows for the measurement of several variables such as rotor speed, armature and field currents, and electromechanical torque developed by the motor.[11]

With PI controller:

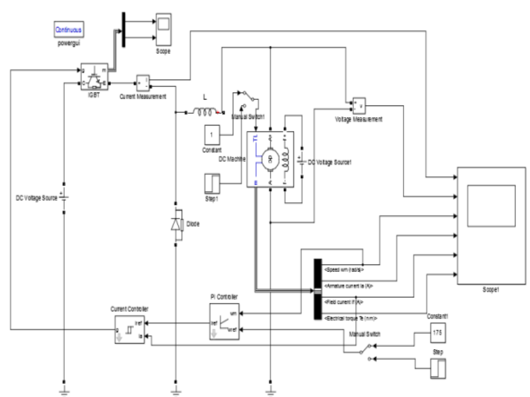


Fig.4.Closed loop speed control Simulink model of SEDM using a conventional PI controller.

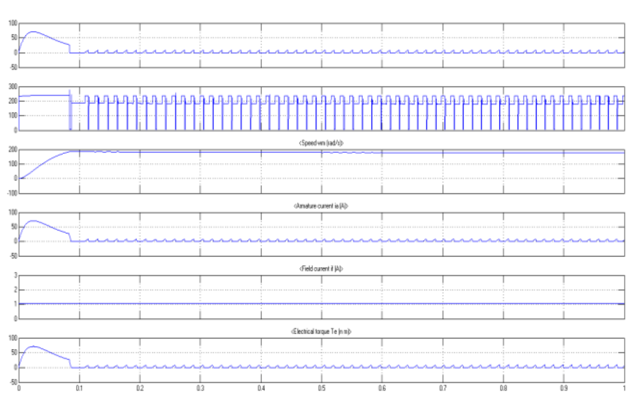


Fig.5.Shows switch current and voltage, Closed loop speed, armature and field currents, and electromechanical torque response using a conventional PI controller.

With FLC Tuned PI:

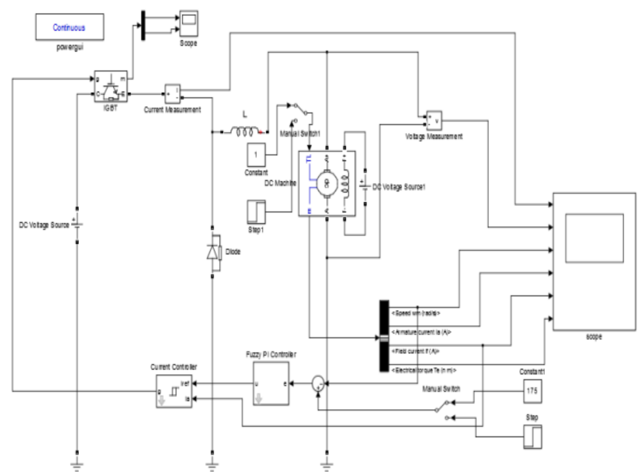


Fig.6.Closed loop speed control Simulink model of SEDM with a FLC tuned PI controller.

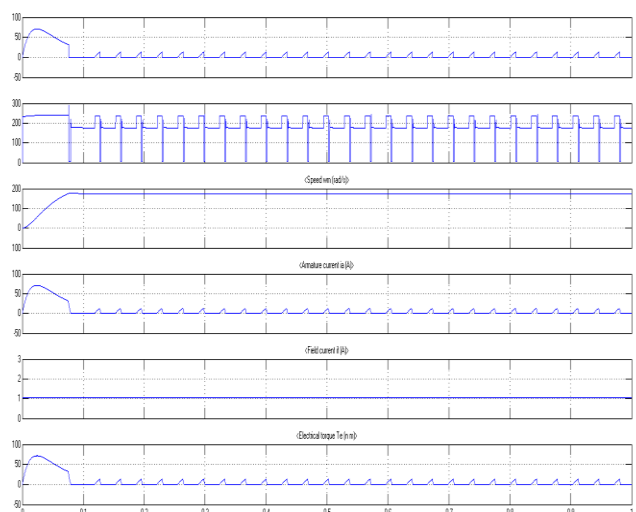
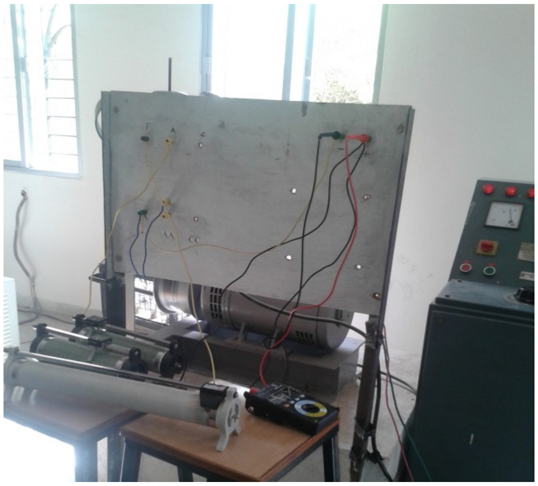


Fig.7.Shows switch current and voltage, Closed loop speed, armature and field currents, and electromechanical torque response with FLC tuned PI controller.



The comparison between the speed of separately excited DC motor using a conventional PI controller and a fuzzy tuned PI controller is as follows:

Table.1.Comparison between results of PI controller and Fuzzy PI controller:

S.NO	Ref Speed (rad/sec)	Controller	Speed Obtained (rad/sec)	Settling Time (sec)
1	175	PI	176.8	0.6
		Fuzzy PI	173.5	0.08
2	150	PI	151.7	0.37
		Fuzzy PI	150	0.09
3	120	PI	121.2	0.72
		Fuzzy PI	120.4	0.1

Conclusion: This paper gives comparison of performance of conventional proportional integral control and fuzzy logic controller for the speed control of DC motor. The two parameters "Kp", "Ki" of conventional PI control need to be constantly adjusted to achieve better response but the parameters adjusted online in self-tuned fuzzy PI in order to achieve better control performance. Fuzzy self-tuning PI controller can automatically adjust PI parameters in accordance with the speed error and therate of speed error-change, so it has better response. Fuzzy PI controller has smaller overshoot and less rising and settling time than conventional PI controller and has better dynamic response.From the simulation results it is concluded that,compared with the conventional PI controller, self-tuning PI controller has a better performance. The self-tuning FLC has better dynamic response, shorter response time, small overshoot, small steady state error, high precision compared to the conventional PI controller.

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