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Hierarchical Control For a Buck Converter Driven DC Motor

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ABSTRACT: DC motors are given preference for industrial applications such as electric locomotives, cranes, goods lifts. But they possess high starting current. This high start-up current must be decreased since it may damage the windings of the motor and increases power consumption. It could be controlled by an appropriate driver system and controller. A hierarchical controller , which is integrated by a control associated with the dc motor based on differential flatness at the high level, and a control related with the dc/dc Buck converter based on a cascade control scheme at the low level. The control at the high level allows the dc motor angular velocity to track a desired trajectory and also provides the desired voltage profile that must be tracked by the output voltage of the dc/dc Buck power converter. In order to assure the cascade control, the inner current loop uses sliding mode control (SMC) and the outer voltage loop uses the Fuzzy Logic Control integrated Proportional-Integral-Derivative (FLC-PID) control.

KEYWORDS: Hierarchical control, cascade control, differential flatness control, sliding mode control, trajectory tracking.

I.INTRODUCTION

DC motor has good speed control respondence , wide speed control range. It is widely used in speed control systems which need high control requirements, such as rolling mill, double-hulled tanker, and high precision digital tools. When it needs control the speed stepless and smoothness, the mostly used way is to adjust the armature voltage of motor. One of the most common methods to drive a dc motor is by using PWM signals with respect to the motor input voltage. However, the underlying hard switching strategy causes unsatisfactory dynamic behaviour, producing abrupt variations in the voltage and current of the motor. The resulting trajectories exhibit a very noisy shape. This causes large forces acting on the motor mechanics and also large currents which detrimentally stress the electronic components of the motor as well as of the power supply. These problems can be addressed by using dc/dc power converters, which allow the smooth start of a dc motor by applying the required voltage in accordance with the one demanded for the performed task, being usually the tracking of either a desired angular velocity trajectory or a desired angular position trajectory.

In particular, the dc/dc Buck power converter has two energy storing elements (an inductor and a capacitor) that generate smooth dc output voltages and currents with a small current ripple, reducing the noisy shape caused by the hard switching of the PWM. Thus, in order to achieve the angular velocity trajectory tracking task of the dc/dc Buck power converter dc motor system, this work focuses on the design of a hierarchical controller.

DC machines are extensively used in many industrial applications such as servo control and traction tasks due to their effectiveness, robustness and the traditional relative ease in the devising of appropriate feedback control schemes, especially those of the PI and PID types. The increasing availability of feedback controller design techniques and the rapid development of circuit simulations programs, such as PSpice, MATLAB offer much wider possibilities to analyse, and redesign, currently used dc motor drive systems.

This paper is organized as follows. In Section II, the existing system with PI controller and in Section III the system with PID controller are shown. In order to evaluate the controller performance, in Section IV, the experimental results obtained are shown. While section V is the comparison between the performance of PI controlled and Fuzzy Logic Control integrated PID controlled buck converter–DC motor system. Finally, conclusions are given in Section VI.

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II. EXISTING SYSTEM

A .DC/DC Buck Converter Driven DC Motor System

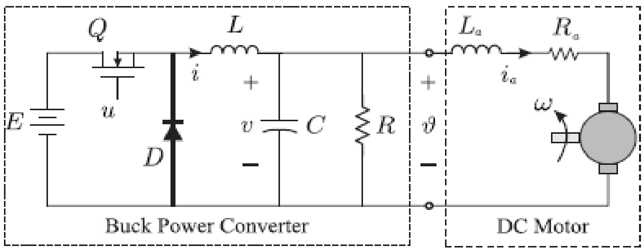

Fig. 1:.DC-DC Buck Power Converter–DC Motor System

The DC motor system fed by a Buck converter under consideration is depicted in Fig 1. The system model is described as follows [1].

$$L\frac{di}{dt} = -v + Eu$$

$$C\frac{dv}{dt} = i - i_a$$

$$L_m\frac{di_a}{dt} = v - R_m i_a - K_e\omega$$

$$J\frac{d\omega}{dt} = K_m i_a - B\omega - T_L$$

where i is the converter input current, i_a is the DC motor armature current, v is the converter output voltage, ω is the motor angular velocity, T_L is the load torque, u is the control input, K_m is the torque constant, K_e is the EMF constant, J is the moment of inertia, and B is the coefficient of friction.

B. DC/DC Buck Power Converter

The basic operation of the buck converter has the current in an inductor controlled by two switches (usually a transistor and a diode). On-state, when the switch is closed, and Off-state, when the switch is open. In the idealized converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off and the inductor has zero series resistance. Further, it is assumed that the input and output voltages do not change over the course of a cycle.

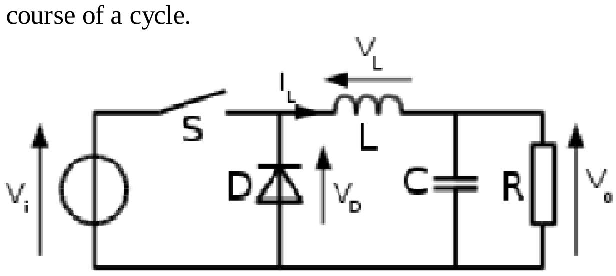

Fig. 2: Buck Converter Circuit Diagram

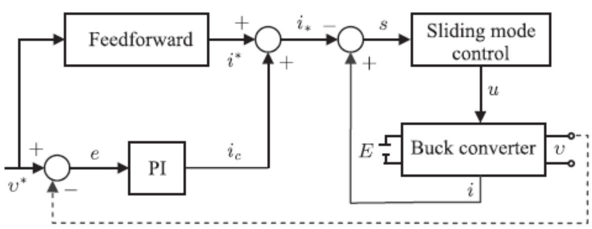

Fig 3: Cascade control for the Buck power converter

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For the Buck converter, the cascade control scheme shown in Fig. 3 is used, where i* is the feedback reference current, υ* is the reference voltage, E, υ, i, and u are as defined previously, and the voltage error, e, is defined by e = υ* − υ. The cascade control for the Buck converter considers a control for the current i and another one for the voltage υ. The inner current loop uses SMC and the outer voltage loop uses a PI control [1].

$$u = \frac{1}{2}[1 - sign(s)]$$

$$s = i - i_*, \; sign\,(s) = \begin{cases} +1, & s \geq 0 \\ -1, & s < 0 \end{cases}$$

$$i_* = i^* + i_c$$

$$= C\frac{dv^*}{dt} + v^*R + k_p e + k_i \int_0^t e\,(\tau)d\tau$$

$$e = v^* - v$$

Where υ* is the time varying desired voltage at the converter output.

C. Hierarchical Control for A DC/DC Buck Power Converter–DC Motor System

In this section, a hierarchical controller is designed with the purpose of carrying out the angular velocity trajectory tracking task for the dc/dc Buck power converter–dc motor system, which is shown in Fig 4. Such a control has the following components.

1. In the high hierarchy level, a control based on differential flatness, ϑ, which executes the angular velocity trajectory tracking task,has been developed for the dc motor. This control corresponds to the desired voltage profile that the output voltage of the Buck converter has to track.
2. In order to assure that the converter output voltage, υ, tracks ϑ, a cascade control is developed in the low hierarchy level. In this control, the inner current loop uses SMC, while the outer voltage loop uses a PI control.

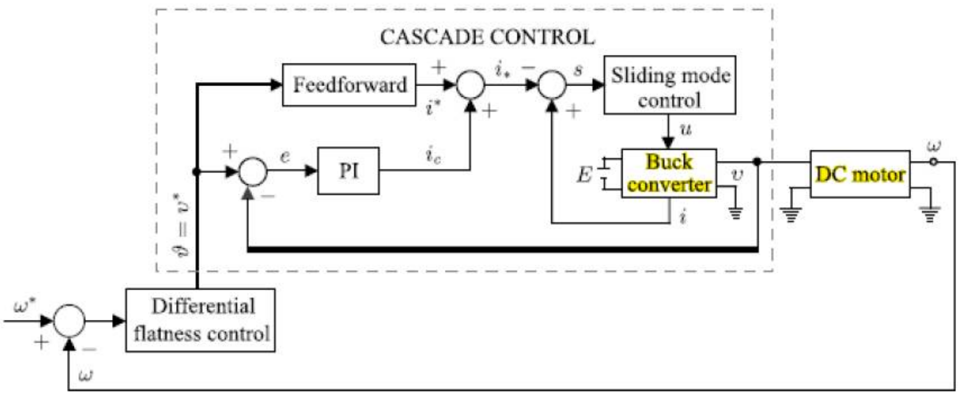

Fig 4: Hierarchical block diagram of the system control

The control based on differential flatness is given as follows:

$$\vartheta = J\frac{L_a}{K_m}\mu_m + \frac{1}{K_m}(BL_a + JR_a)\dot{\omega} + (\frac{BR_a}{K_m} + K_e)\omega$$

Where

$$\mu_m = \ddot{\omega}^* - \gamma_2(\dot{\omega} - \dot{\omega}^*) - \gamma_1(\omega - \omega^*) - \gamma_0 \int_0^t (\omega - \omega^*)d\tau$$

Such that, when $t \to \infty$then $\omega \to \omega^*$.

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III.PROPOSED SYSTEM

In the cascade control is developed in the low hierarchy level, the inner current loop uses sliding mode control while the outer voltage loop uses a feed forward and a proportional-integral control. In the high hierarchy level, a control based on differential flatness, which executes the angular velocity tracking task has been developed for the dc motor. In order to achieve the latter, here a cascade control at the low level is designed, considering a sliding mode control for the inner current loop and a proportional-integral-derivative (PID) control for the outer voltage loop. This paper applies fuzzy logic control algorithm for PID controllers to deal with those motion control systems having constant disturbance. A Fuzzy Logic Control Integrated PID controller is designed for the system to meet the desired performance specifications by using Fuzzy Logic Control.

The manner of obtaining the parameters of PID controllers that satisfy the performance requirement has been addressed in many studies [6,7]. The well-known method, Ziegler–Nichols method [7], provides a systematic tuning method for the PID parameters; this method has good load disturbance attenuation but shows unsatisfactory performance, with a large overshoot and long settling time. For improving systems' performance, e.g., rise time, overshoot, and integral of the absolute error, many studies are attempting to incorporate features on the basis of the experiences of experts with regard to PID gain scheduling, and the use of fuzzy logic seems to be particularly appropriate. Recently, fuzzy PID controllers have been presented and investigated, and their satisfactory performance in various plants have been revealed.

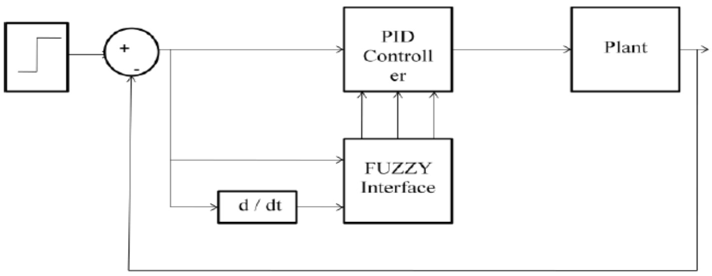

Fig 7. Fuzzy integrated PID controller

de\e	NB	NM	NS	ZE	PS	PM	PB
NB	VB	MB	VB	VB	VB	B	VB
NM	MB	MB	MB	MB	B	B	B
NS	B	MB	B	B	MB	B	VB
ZE	ZE	MB	ZE	MS	S	B	S
PS	B	MB	B	B	VB	B	VB
PM	MB	MB	B	B	VB	B	B
PB	VB	MB	VB	VB	VB	B	VB

Table1.Fuzzy rules for Kp

The fuzzy rule table for Kp is given in Table 1. The Table 2 contains the fuzzy rule base for Ki.

de\e	NB	NM	NS	ZE	PS	PM	PB
NB	M	M	M	M	M	S	M
NM	M	M	S	MS	M	M	MS
NS	S	S	S	S	S	M	S
ZE	MS	ZE	MS	ZE	MS	S	S
PS	S	MS	S	S	S	S	S
PM	S	M	M	S	S	S	MS
PB	M	M	M	M	M	MS	M

Table2.Fuzzy rules for Ki

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Table 3 contains the fuzzy rule base for the parameter Kd in the fuzzy integrated PID controller.

de\e	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	S	S	M	MB	B	VB
NM	S	M	M	M	B	MB	VB
NS	S	B	B	MB	VB	VB	VB
ZE	M	MB	MB	MB	VB	VB	VB
PS	B	VB	VB	VB	VB	VB	VB
PM	MB	B	B	VB	VB	VB	VB
PB	VB	VB	VB	VB	VB	VB	VB

Table3.Fuzzy rules for Kd

IV.SIMULATION STRATEGY

Below is the simulation model for the hierarchical control of a Buck converter driven DC motor with fuzzy integrated PID controller.

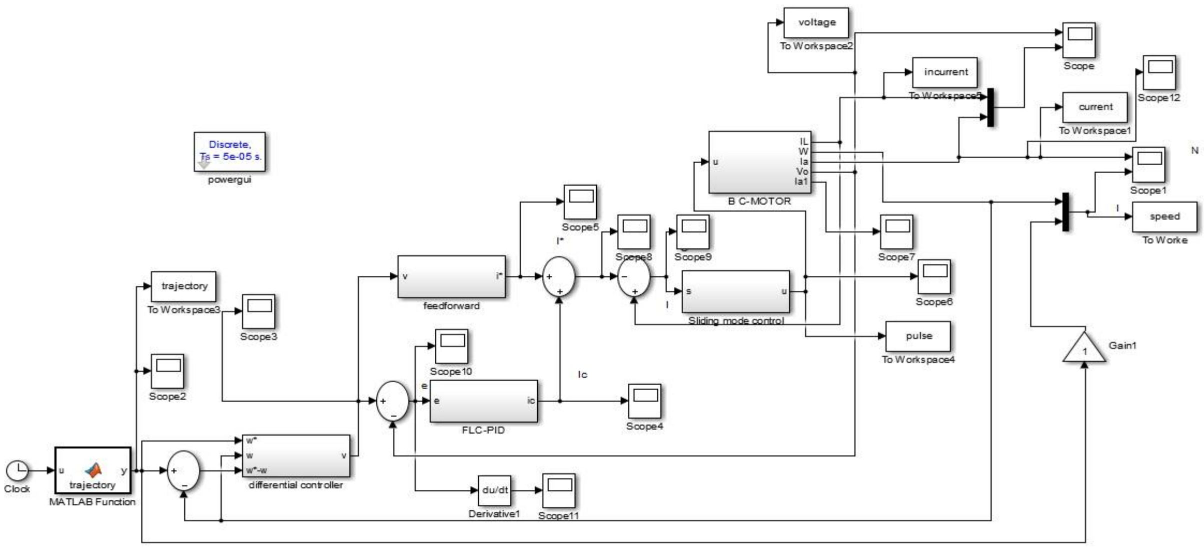

Fig 8: SIMULINK block diagram of System with FLC- PID Controller

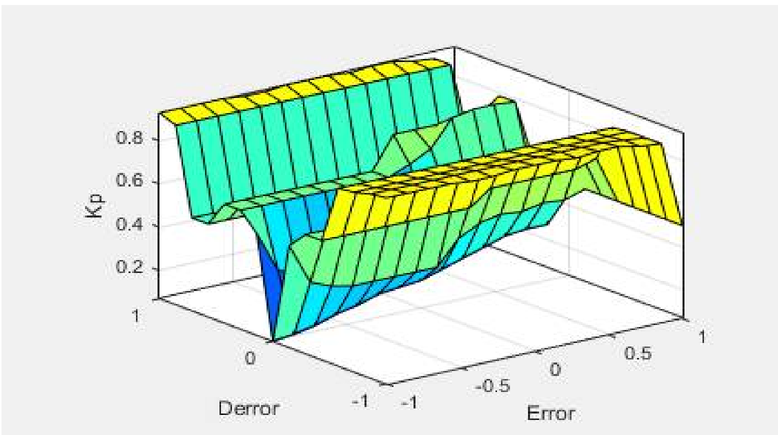

Fig 9. Surface viewer for Kp

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The fig 9 shows the surface view of the parameter Kp.

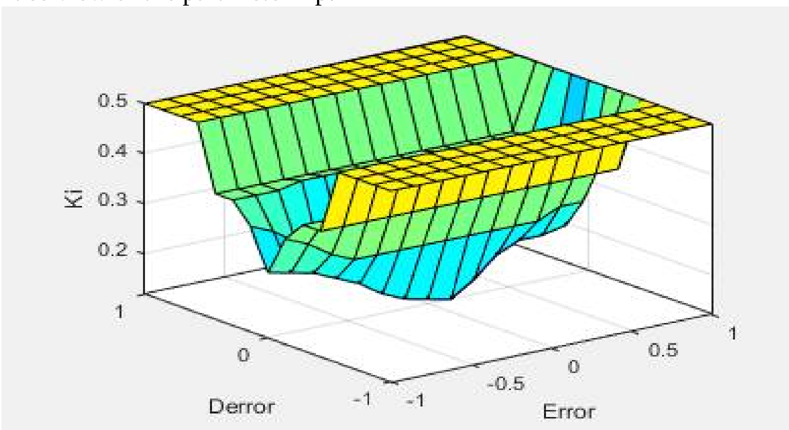

Fig 10. Surface viewer for Ki

The fig 10 and 11 shows the surface view of the parameter Ki and Kd respectively.

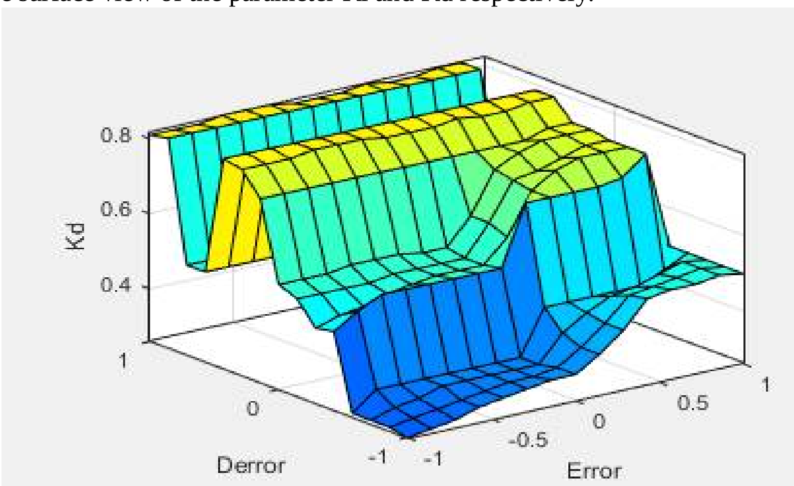

Fig 11. Surface viewer for Kd

V. RESULT AND DISCUSSION

The simulation result of the Buck converter driven DC motor is given below, fig 12 showsthe control pulse for the converter.

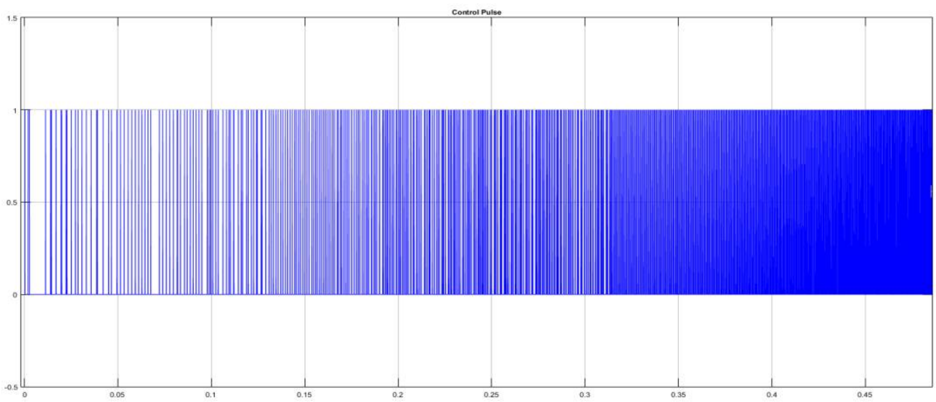

Fig12. Control Pulse for buck converter

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Fig 13 shows the angular velocity trajectory tracking task of the converter-motor system.

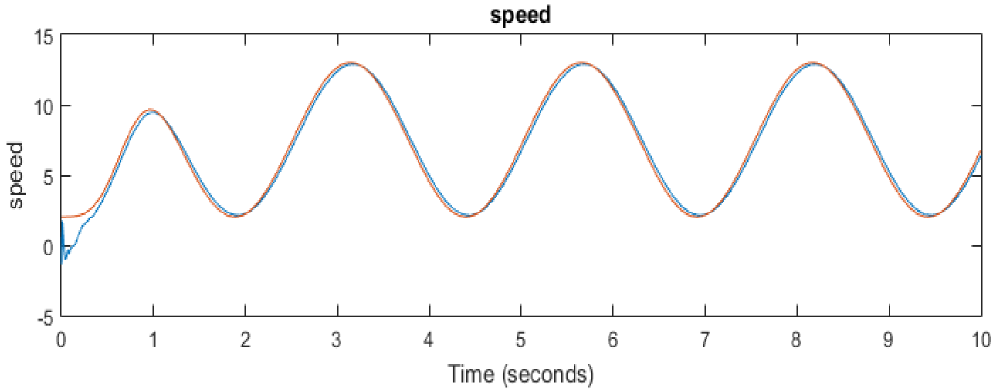

Fig 13.Trajectory tracking of motor speed

Fig 14 shows the smooth starting current of the motor.

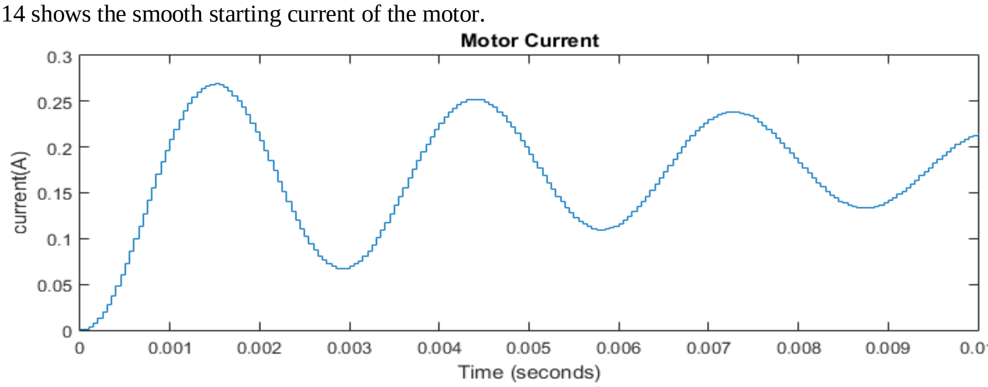

Fig 14. Starting current of motor

VI.CONCLUSION

A technique for improving the smooth running of a buck converter for controlling DC motor is developed. The PID controller parameters are optimized using fuzzy logic controller eliminate the steady state error of the system. According to the experimental results, the main purpose of this paper was successfully achieved, since the angular velocity of the motor tracks a desired angular velocity trajectory.

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