

PID And Sliding Mode Control of Buck Power Converter as a Smooth Starter for DC Motor

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ABSTRACT: In this paper, the design of a hierarchical controller for dc/dc buck power converter, in order to achieve the angular velocity tracking task of the dc motor is presented. To this end, a cascade control is developed in the low hierarchy level. In this control, 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 the simulated annealing algorithm for PID controllers to deal with those motion control systems having constant disturbance. A Simulated Annealing PID controller is designed for the system to meet the desired performance specifications by using SA optimization method. The main goal is to eliminate the steady state error of the system. The designed controller is tested using MATLAB-simulink software and desired result is obtained confirming the validity of the proposed controller.

KEYWORDS: DC–DC converter, Sliding Mode Control (SMC), Buck Power Converter, PID controller, simulated annealing algorithm

I. INTRODUCTION

DC motors are given preference in many industrial applications by reason of some advantages provided by their working characteristics. DC motors are widely used in systems with high control requirements. Thus, rolling mills, double-hulled tankers, and high-precision digital tools can be mentioned as examples of such systems. Frequently, dc-to-dc power converters are used as dc motor drives, which apply the required voltage to the dc motor in accordance with the demanded task represented by the desired angular velocity profile or angular position reference trajectory[1].

The literature relating to dc/dc power-converters-driven dc motors is as follows. In 2000, Lyshevski [3] proposed fourth order mathematical models for some combinations of dc/dc power converters coupled to a dc motor and, additionally, designed classical proportional-integral (PI) controllers for the regulation of the motor angular velocity. In [4], a smooth starter, based on the differential flatness approach, to regulate the velocity of a dc motor powered by a dc/dc Buck converter was presented. Other work, introduced in 2010 by Ahmad *et al.* [2], presents, through numerical simulations, a comparative evaluation of the performance of the PI, PI of fuzzy logic type, and LQR controllers for the angular velocity trajectory tracking task of a dc motor powered by a dc/dc Buck converter. Similarly, in 2011, Sureshkumar and Ganeshkumar [6] compared for the same system, via numerical simulations, the performance of both PI and backstepping controllers associated with the regulation of the angular velocity of the aforementioned system. Additionally, important contributions related to the connection of other dc/dc power converters and dc motors have been reported in [5], [7]–[14].

The main contribution of this paper is to propose a hierarchical controller that carries out the angular velocity trajectory tracking task for the dc/dc Buck converter–dc motor system. To achieve this, as a variation of i) two independent

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controllers are designed; one for the dc motor (via differential flatness) and another via the cascade scheme (through the SMC and PID control) for the Buck converter, which are then interconnected in order to work as a whole.

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 PID controlled buck converter–DC motor system. Finally, conclusions are given in Section VI.

II. EXISTING SYSTEM

A. DC/DC BUCK POWER CONVERTER–DC MOTOR SYSTEM

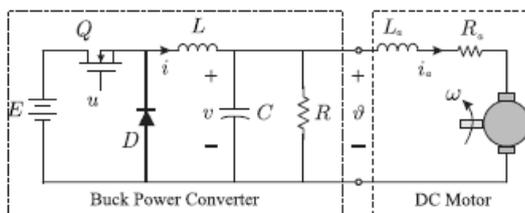


Fig 1: Dc/Dc Buck Power Converter–Dc Motor System

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

$$\begin{aligned} L \frac{di}{dt} &= -v + Eu \\ C \frac{dv}{dt} &= i - i_a \\ L_m \frac{di_a}{dt} &= v - R_m i_a - k_e \omega \\ J \frac{d\omega}{dt} &= k_m i_a - f \omega - T_L \end{aligned}$$

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 f 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.

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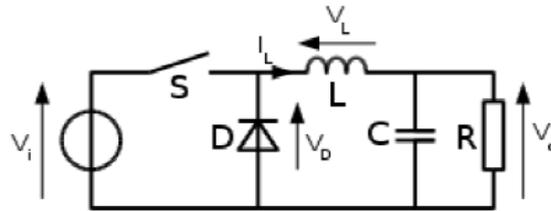


Fig. 2: Buck Converter Circuit Diagram

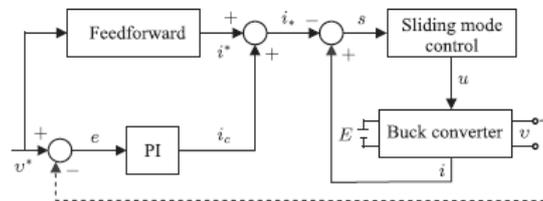


Fig 3: Cascade control for the Buck power converter

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

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

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

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

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

$$e = v^* - v$$

Where v^* 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, v , 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.

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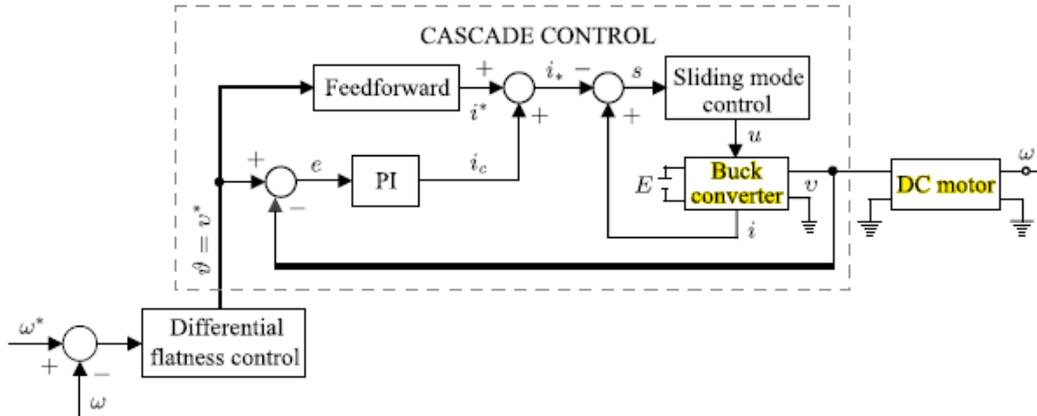


Fig 4: Hierarchical block diagram of the system control

The control based on differential flatness is given as follows [1] :

$$\vartheta = \frac{JL_a}{k_m} \mu_m + \frac{1}{k_m} (bL_a + JR_a) \dot{\omega} + \left(\frac{bR_a}{k_m} + k_e \right) \omega$$

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 $t \rightarrow \infty$ then $\omega \rightarrow \omega^*$.

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 the simulated annealing algorithm for PID controllers to deal with those motion control systems having constant disturbance. A Simulated Annealing PID controller is designed for the system to meet the desired performance specifications by using SA optimization method.

A. PID Controller

Proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable [16].

The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be

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described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point, and the degree of system oscillation.

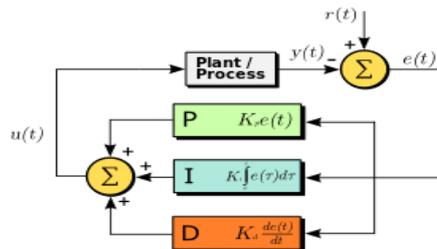


Fig: 5 Block diagram of a PID controller in a feedback loop

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$$

Where K_p , K_i , K_d are the parameters of the PID controller which are tuned using Simulated annealing algorithm.

B. Simulated Annealing Algorithm

Simulated Annealing is a numerical optimization technique based on the principles of thermodynamics. Resembles the cooling process of molten metals through annealing. The simulated annealing is based on the following characteristics Annealing in metals ,Heat the solid state metal to a high temperature ,cool it down very slowly according to a specific schedule. If the heating temperature is sufficiently high to ensure random state and the cooling process is slow enough to ensure thermal equilibrium, then the atoms will place themselves in a pattern that corresponds to the global energy minimum of a perfect crystal [15].

Steps Involved [16]:

Step 1: Initialize – Start with a random initial placement. Initialize a very high “temperature”.

Step 2: Move – Perturb the placement through a defined move.

Step 3: Calculate score – calculate the change in the score due to the move made.

Step 4: Choose – Depending on the change in score, accept or reject the move. The probability of acceptance depending on the current “temperature”.

Step 5: Update and repeat– Update the temperature value by lowering the temperature. Go back to Step 2. The process is done until “Freezing Point” is reached.

C. Simulation of System with PID Controller

In order to investigate the proposed controller performance and accuracy, MATLAB/SIMULINK and its facilities is used. Fig. 6 show the SIMULINK block diagram of System With PID Controller. Simulations are performed on the proposed system with the parameter values in [1].

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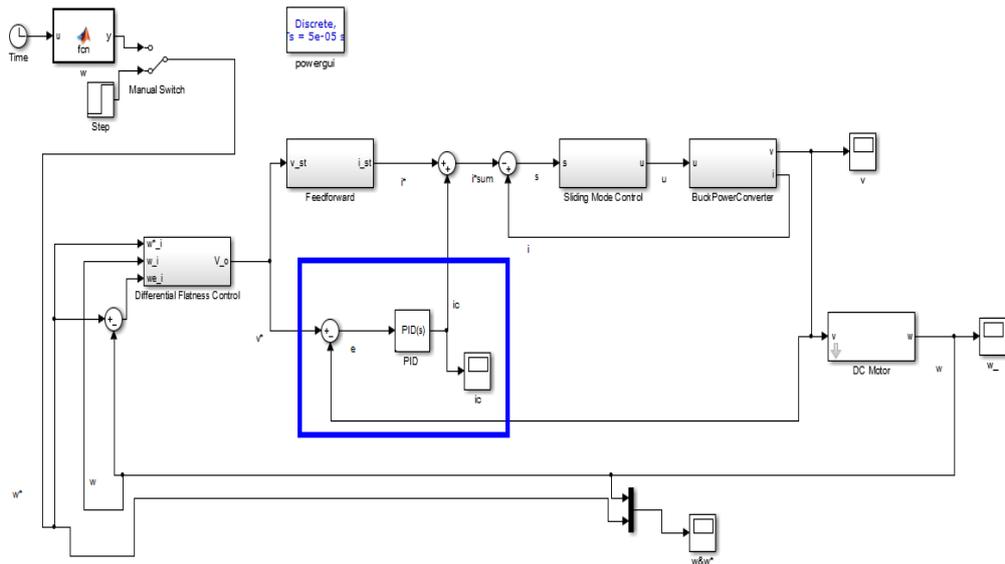


Fig 6: SIMULINK block diagram of System with PID Controller

IV. EXPERIMENTAL RESULTS

Figure 7-10 shows the buck power converter output voltage, output current and DC motor speed. The results shows that the proposed system has improved the performance of the system.

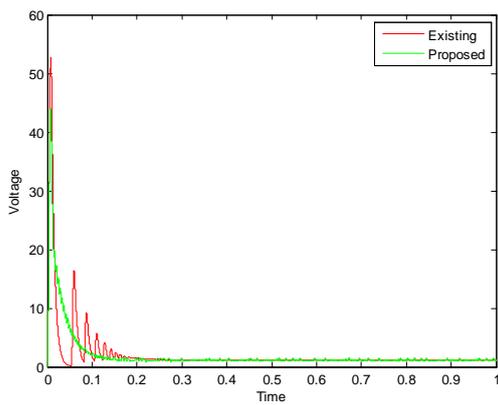


Fig: 7 Buck power converter output voltage for step input

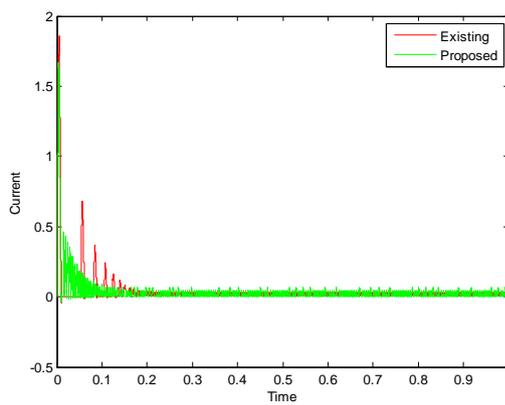


Fig: 8 Buck power converter output current for step input

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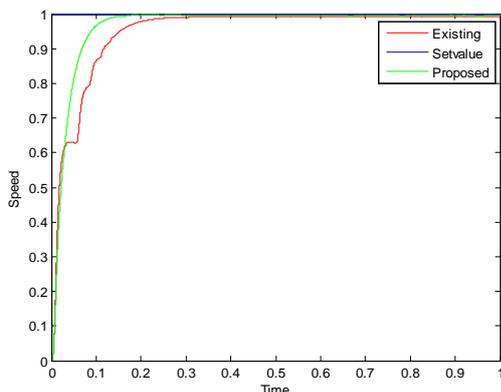


Fig: 9 DC motor speed for step input

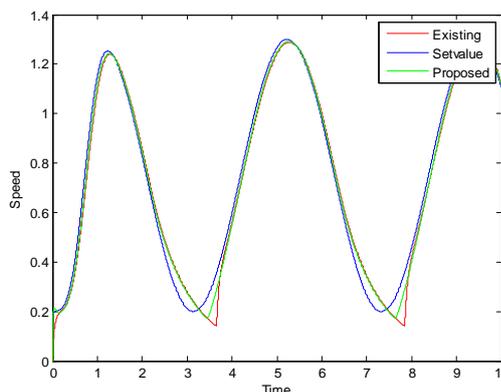


Fig: 10 DC motor speed for non-linear input

V. COMPARISON

Comparison has been made between the performance of PI controlled and PID controlled buck converter–dc motor system and is presented in table 1. it clearly shows the improved performance of PID controller over PI controller in terms of rise time, peak time, peak overshoot and overall system stability.

Parameters	With PI controller	With PID controller
Risetime	0.1070	0.0439
SettlingTime	0.1857	0.0806
SettlingMin	0.8933	0.8979
SettlingMax	0.9924	1.0042
Overshoot	0.6629	0.0010
Undershoot	0	0
Peak	0.9924	0.9924
peakTime	0.6983	0.1897

Table 1: Performance Parameter Comparison

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 SA optimizer to 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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