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A Novel Speed Control Technique for A Buck Power Converter Driven DC Motor

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ABSTRACT
A DC motor is an electrical machine that converts direct current electrical power in to mechanical power. The speed of a DC motor can be controlled by changing the voltage applied to the armature. The parameter which includes speed, voltage, and current of a DC machine is controlled using DC/DC buck power converter. This paper deals with a Hierarchical control system which involves three stages to control the parameters of DC motor. This Hierarchical controller is designed with a control associated with 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 output voltage of the DC/DC Buck power converter. The lower level cascade control is designed by considering sliding mode control for inner current loop and PI control for the outer voltage loop. This control strategy is tested through experiments using Mat lab- Simulink. The obtained results show that the desired the voltage profile is well tracked under abrupt variations in the system parameters and that the controller is robust in such operation conditions.

Keywords:Hierarchical Controller, DC/DC Buck Power Converter, DC Motor, Proportional-Integral (PI) Control.

I. INTRODUCTION

A large number of motors are being used for general purposes in our surroundings from household equipment to machine tools in industrial facilities. The electric motor is now a necessary and indispensable source of power in many industries. The function and the performance required for these motors are wide-ranging. DC motors are widely used in systems with high control requirements. Generally in rolling mills, double- Hulled tankers, and high precision digital tools can be mentioned as examples of such systems. Generally, to control the step less velocity and smoothness, adjustment of the armature voltage of the motor is used while, certainly, applying PWM signals with respect to the motor input voltage is one of the methods most employed to drive a DC motor. However, the underlying hard switching strategy causes an unsatisfactory dynamic behavior, producing abrupt variations in the voltage and current of the motor. 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.

A buck converter is a step-down DC to DC converter. 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. In order to achieve the angular velocity trajectory tracking task, a hierarchical control scheme, similar to the ones used in for mobile robots, is presented. To accomplish this two independent controllers are designed; one for the DC motor (via differential flatness) and another via the cascade scheme (through the SMC and PI control) for the Buck converter, which are then interconnected in order to work as a whole. Additionally, experimental validation of the proposed hierarchical controller's performance is included, showing how the trajectory tracking task is successfully accomplished, even when abrupt variations of the system parameters appear, so exhibiting the robustness of the controller presented. The importance of such experimental validation is that it could lead to a practical application of the controller herein presented.

1.1 Buck Power Converter

A **buck converter** (**step-down converter**) is a DC-to-DC power converter which steps down voltage (while stepping up current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) typically containing at least two semiconductors (a diode and a transistor, although modern buck converters frequently replace the diode with a second transistor used for synchronous rectification) and at least one energy storage element, a capacitor, inductor, or the two in combination[1]. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

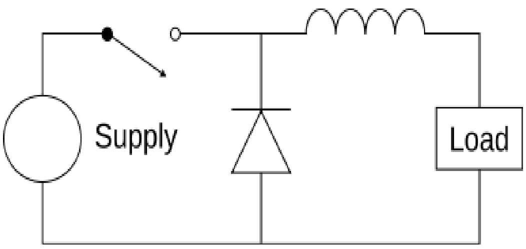


Fig.1 Block diagram of Buck converter

1.1.1 Operation

The mode of operation of buck converter is best understood in terms of the relation between current and voltage of the inductor. Beginning with the switch open (off-state), the current in the circuit is zero. When the switch is first closed (on-state), the current will begin to increase, and the inductor will produce an opposing voltage across its terminals in response to the changing current. This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load. Over time, the rate of change of current decreases, and the voltage across the inductor also then decreases, increasing the voltage at the load. During this time, the inductor stores energy in the form of a magnetic field. If the switch is opened while the current is still changing, then there will always be a voltage drop across the inductor, so the net voltage at the load will always be less than the input voltage source. When the switch is opened again (off-state), the voltage source will be removed from the circuit, and the current will decrease. The decreasing current will produce a voltage drop across the inductor (opposite to the drop at on-state), and now the inductor becomes a Current Source. The stored energy in the inductor's magnetic field supports the current flow through the load. This current, flowing while the input voltage source is disconnected, when concatenated with the current flowing during on-state, totals to current greater than the average input current (being zero during off-state). The "increase" in average current makes up for the reduction in voltage, and ideally preserves the power provided to the load. During the off-state, the inductor is discharging its stored energy into the rest of the circuit. If the switch is closed again before the inductor fully discharges (on-state), the voltage at the load will always be greater than zero.

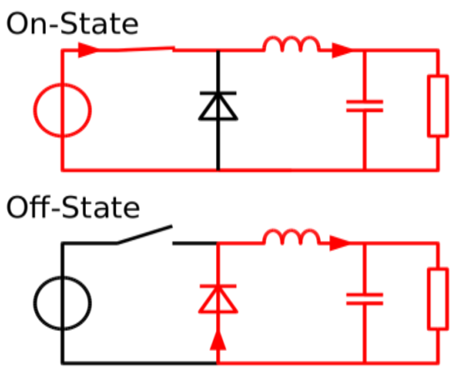


Fig. 2: The two circuit configurations of a buck converter:

2.Control Schemes for Buck Converter

The voltage profile thatis required by the DC motor to track the desired angular velocity trajectory must be produced by a Buck power converter. Therefore, it naturally arises the need to develop a control scheme for the converter that allows toreproduce the desired voltage profile. The Cascade control scheme for buck converter is given below.[2]

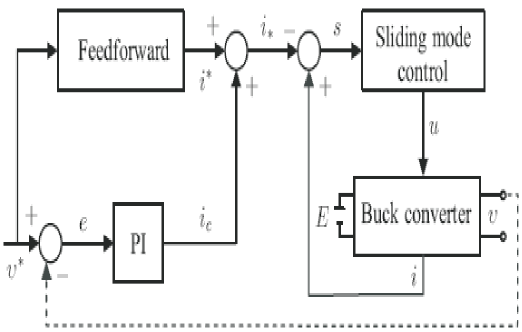


Fig.3 Buck Converter with cascade control scheme

The cascade control for the Buck converter considers a control for the current i and another one for the voltage. The inner current loop uses SMC and the outer voltage loop uses a PI control[3][6]. The following proposition summarizes the proposed controller.

$i^*$is the feedback reference current

i is the inductor current, v is voltage across capacitor, u is control input.

Voltage error e= v* − v.

v* is the time varying desired voltage at converter output.

$$u = \frac{1}{2}[1 - \text{sign}(s)],$$
$$s = i - i_*, \qquad \text{sign}(s) = \begin{cases} +1, & s \geq 0, \\ -1, & s < 0, \end{cases}$$
$$i_* = i^* + i_c$$
$$= \underbrace{C\frac{dv^*}{dt} + \frac{v^*}{R}}_{i^*} + \underbrace{k_p e + k_i \int_0^t e(\tau)d\tau}_{i_c},$$
$$e = v^* - v,$$

1.3Buck power converter fed DC Motor

The DC motor system fed by a Buck converter under consideration is given in fig.

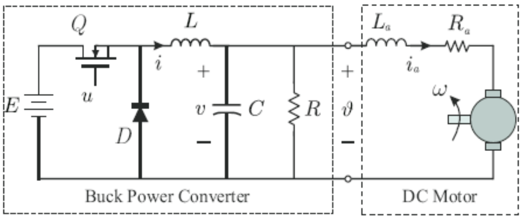


Fig.4 Buck power converter-DC Motor system

The above switched converter is associated with following model.

$$L\frac{di}{dt} = -V + E_u$$
$$C\frac{dv}{dt} = i - \frac{v}{R}$$
$$L_a\frac{di_a}{dt} = V - R_a i_a - k_e \omega$$
$$J\frac{d\omega}{dt} = -b\,\omega + k_m i_a$$

where i is the converter input current, i_a is the DC motor armature current, v is the converter output voltage, ωis 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, Jis the moment of inertia, and B is the coefficient of friction.

1.2 Novel Hierarchical control scheme for Buck power converter fed DC motor.

In this section, a hierarchical controller[4][5] 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 5. The hierarchical control scheme includes.

1. 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.

Finally, by means of the hierarchical control approach, the controllers developed in 1) and 2) are interconnected to carry out the angular velocity trajectory tracking task of the system.

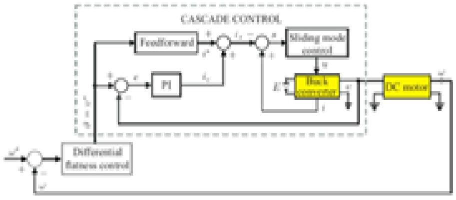


Fig.5 Block diagram for Hierarchical control scheme.

The control based on differential flatness is given as follows

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

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

1.4Dc/Dc Buck Power Converter Model Based On Hierarchial Control

Below is the simulation model for the hierarchicalControl of a Buck converter driven DC motor

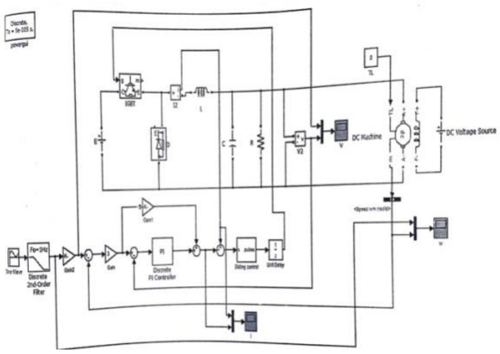
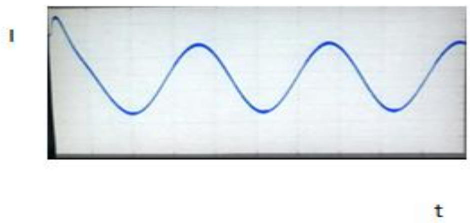


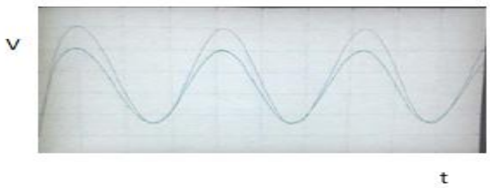
Fig.6 Simulation diagram for Hierarchical control scheme.

1.3 Simulation Results

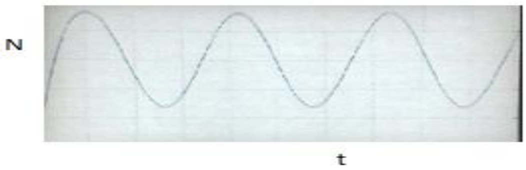
Current waveform observed in simulink



Voltage waveform observed in Simulink



Speed Waveform observed in Simulink



II. CONCLUSION

In this paper the Heirarchial control scheme for a buck power converter fed DC Motor is proposed.Specifically, the hierarchical controller is composed of two controllers. The first deals with the control of the DC motor and the second with the control of the Buck converter. 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 output voltage of the DC/DC Buck power converter. The lower level cascade control is designed by considering sliding mode control for inner current loop and PI control for the outer voltage loop.The experimental results show the proposed controller presents a good performance under abrupt variations of system parameters,which **would make possible to use this controller in** practical applications.

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