Application of DC/DC Buck Power Converter in DC Motor for Speed Controlling Using PI Controller

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ABSTRACT

DC motor widely used-high precision digital controls. Speed control of dc motor is achieved with smooth starter by using buck converter. Hard switching causes unsatisfactory dynamic behaviour produces abrupt variations in the V & I of the motor overcome by dc-dc buck power converter by PI controller. A separately excited dc motor is used for this simulation. The proposed system with PI control is used as outer voltage control loop. Dc-dc buck converter is mainly used for regulate the desired output voltage level and maintain DC motor speed as constant. Any change in torque does not affect the speed of the motor. Step less velocity and smoothness in armature voltage control with PWM technique is used.

KEYWORDS: *Smooth Starter, DC/DC Buck Power Converter, DC Motor, Proportional-Integral (PI) Control.*

I. INTRODUCTION

DC motors are widely used in systems with high precision control requirements. Thus, 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. Power converters, which allow the smooth start of a DC motor by applying the required voltage.

A large number of motors are being used for general purposes in our surroundings from house-hold 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. When focusing attention on the speed control segment of the motor market, servo and stepping motors control their speed with a pulse train, while the induction motor and the brushless DC motor control speed with an external resistor and/or DC voltage. This article explains the structure, the speed control principle, and the features of the following three product groups that can control the speed relatively easily by using an analog input. x AC speed control motor x Brushless DC motor unit x Inverter unit

II. SPEED CONTROL METHODS OF THE VARIOUS SPEED CONTROL MOTORS

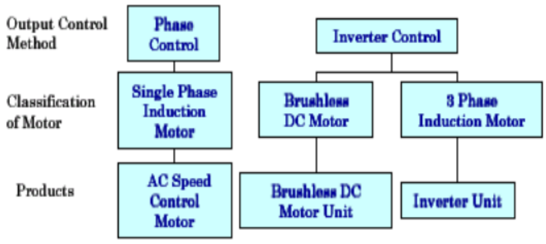


Fig. 1 Classification of speed control motors

The output control method of a speed control circuit can be divided roughly into two groups: phase control and inverter control, which make up the product groups shown in Fig. 1.

AC speed control motors

Construction of motor As shown in Fig. 2, the construction of the single phase and three-phase induction motors includes a stator where the primary winding is wound and a basket-shaped, solid aluminum die cast rotor. The rotor is low-cost because the structure is simple and does not use a magnet.

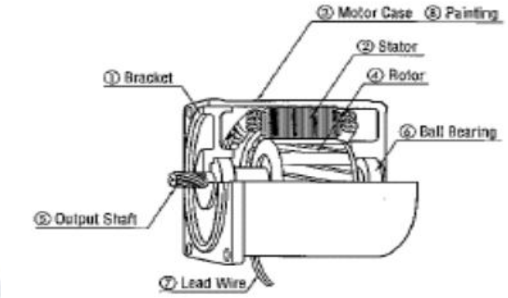


Fig. 2 Construction of induction motor

When the speed of this motor is to be controlled, a tacho-generator is used to detect the speed and is attached to the motor as shown in Fig. 3. The tacho-generator is made of a magnet connected directly to the motor shaft and a stator coil that detects the magnetic poles, and generates an AC voltage at 12 cycles per revolution. Since this voltage and frequency increase with a rise of the rotational speed, the rotational speed of the motor is controlled based on this signal.

Principle of speed control

Rotational speed N of an induction motor can be shown by the expression (1). When the voltage applied to the motor is increased and decreased, the slip s changes, then the rotational speed N will change.

$$N = 120 \cdot f \cdot (1 - s) / P \quad \text{-------} \ (1)$$

N: Rotational speed [r/min]

F: Frequency 〔Hz〕

P: Number of poles of a motor

S: Slip

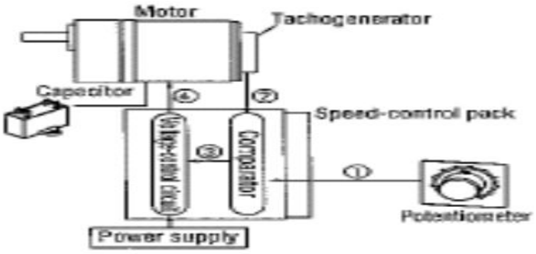


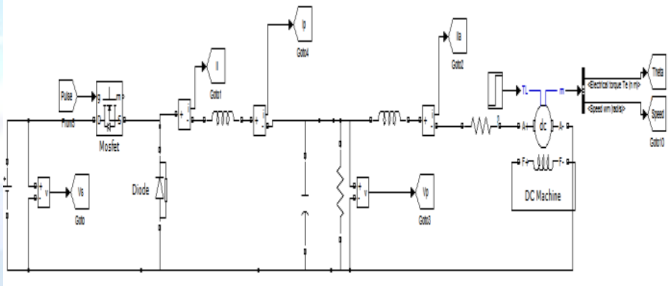
Fig. 3 AC speed control motor system

Control of a DC/DC Buck Power Converter

From the results obtained in the previous section, it is observed that the voltage profile ϑ is required by the dc motor to track the desired angular velocity trajectory ω∗. It must be remembered that ϑ is produced by a Buck power converter. Therefore, it naturally arises the need to develop a control scheme for the converter that allows to reproduce the desired voltage profile ϑ. Thus, the purpose of this section is to present a cascade control for the Buck converter similar to those presented for Boost, Buck–Boost, noninverting Buck–Boost, and Cuk converters in [8]–[11], respectively. It is important to mention that those controllers were only designed for the regulation task. In contrast to those controllers, this section gives the solution for the voltage trajectory tracking task of the Buck converter output.

Control Laws Integration

In order to achieve that the dc motor, via the dc/dc Buck converter, accomplishes the angular velocity trajectory tracking task, a hierarchical control scheme, similar to the ones used in formobile robots, is presented. Therefore, connection of the controllers proposed in previous sections is necessary. Thus, Fig. 3 shows a block diagram of the connection of the controllers and the system.



III. BUCK CONVERTER

A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode), an inductor and a capacitor.

The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess power as heat; also, output voltage isn't regulated (varies with input voltage). Buck converters, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating, making them useful for tasks such as converting the 12–24 V typical battery voltage in a laptop down to the few volts needed by the processor.

Continuous mode

A buck converter operates in continuous mode if the current through the inductor (I_L) never falls to zero during the commutation cycle. In this mode, the operating principle is described by the chronogram in figure:

- When the switch pictured above is closed (On-state, top of figure 2), the voltage across the inductor is $V_L = V_i - V_o$. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it;
- When the switch is opened (off state, bottom of figure 2), the diode is forward biased. The voltage across the inductor is $V_L = -V_o$(neglecting diode drop). Current I_L decreases.

The energy stored in inductor L is

$$E = \frac{1}{2} L \times I_L^2$$

Therefore, it can be seen that the energy stored in L increases during On-time (as I_L increases) and then decreases during the Off-state. L is used to transfer energy from the input to the output of the converter.

The rate of change of I_L can be calculated from:

$$V_L = L \frac{dI_L}{dt}$$

With V_L equal to $V_i - V_o$ during the On-state and to $-V_o$ during the Off-state. Therefore, the increase in current during the On-state is given by:

$$\Delta I_{L_{on}} = \int_0^{t_{on}} \frac{V_L}{L}\, dt = \frac{(V_i - V_o)}{L} t_{on}$$

Identically, the decrease in current during the Off-state is given by:

$$\Delta I_{L_{off}} = \int_0^{t_{off}} \frac{V_L}{L}\, dt = -\frac{V_o}{L} t_{off}$$

If we assume that the converter operates in steady state, the energy stored in each component at the end of a commutation cycle T is equal to that at the beginning of the cycle. That means that the current I_L is the same at t=0 and at t=T (see figure 4). Therefore,

So we can write from the above equations:

$$\frac{(V_i - V_o)}{L} t_{on} - \frac{V_o}{L} t_{off} = 0$$

It is worth noting that the above integrations can be done graphically: In figure 4, $\Delta I_{L_{on}}$ is proportional to the area of the yellow surface, and $\Delta I_{L_{off}}$ to the area of the orange surface, as these surfaces are defined by the inductor voltage (red) curve. As these surfaces are simple rectangles, their areas can be found easily: $(V_i - V_o)\, t_{on}$ for the yellow rectangle and $-V_o t_{off}$ for the orange one. For steady state operation, these areas must be equal.

As can be seen on figure 4, $t_{on} = DT$ and $t_{off} = (1-D)T$. D is a scalar called the duty cycle with a value between 0 and 1. This yields

$$(V_i - V_o)DT - V_o(1-D)T = 0$$

$$\Rightarrow V_o - DV_i = 0$$

$$\Rightarrow D = \frac{V_o}{V_i}$$

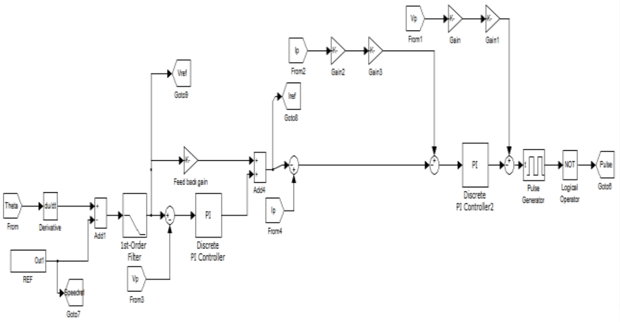
From this equation, it can be seen that the output voltage of the converter varies linearly with the duty cycle for a given input voltage. As the duty cycle D is equal to the ratio between t_{On} and the period T, it cannot be more than 1. Therefore, $V_o \leq V_i$. This is why this converter is referred to as step-down converter.

So, for example, stepping 12 V down to 3 V (output voltage equal to a fourth of the input voltage) would require a duty cycle of 25%, in our theoretically ideal circuit.

Discontinuous mode

In some cases, the amount of energy required by the load is small enough to be transferred in a time lower than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle. This has, however, some effect on the previous equations.

Controlling Circuit:



PI Contoller:

The general block diagram of the PI speed controller is shown in Figure 2

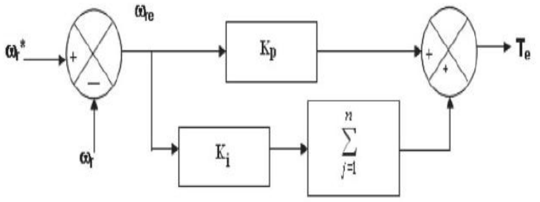


FIG. 2. Block diagram of PI speed controller.

The output

Of the speed controller (torque command) at n-th instant is expressed as follows:

$Te(n)=Te(n-1)+Kp\_\omega re(n)+Ki\omega re(n)$ (10)

Where Te (n) is the torque output of the controller at the n-th instant, and Kp and Ki the

proportional and integral gain constants, respectively.

A limit of the torque command is imposed as

$$T_{e(n+1)} = \begin{cases} T_{e\max} & \text{for} \quad T_{e(n+1)} \geq T_{e\max} \\ -T_{e\max} & \text{for} \quad T_{e(n+1)} \leq -T_{e\max} \end{cases}$$

The gains of PI controller shown in (10) can be selected by many methods such as trial and error method, Ziegler–Nichols method and evolutionary techniques-based searching. The numerical values of these controller gains depend on the ratings of the motor.

Advantages and disadvantages

The integral term in a PI controller causes the steady-state error to reduce to zero, which is not the case for proportional-only control in general. The lack of derivative action may make the system more steady in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs. Without derivative action, a PI-controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach setpoint and slower to respond to perturbations than a well-tuned PID system may be.

Integral Action and PI Control

Like the P-Only controller, the Proportional-Integral (PI) algorithm computes and transmits a controller output (CO) signal every sample time, T, to the final control element (e.g., valve, variable speed pump). The computed CO from the PI algorithm is influenced by the controller tuning parameters and the controller error, e(t). PI controllers have two tuning parameters to adjust. While this makes them more challenging to tune than a

P-Only controller, they are not as complex as the three parameter PID controller.

Integral action enables PI controllers to eliminate offset, a major weakness of a P-only controller. Thus, PI controllers provide a balance of complexity and capability that makes them by far the most widely used algorithm in process control applications.

The PI Algorithm

While different vendors cast what is essentially the same algorithm in different forms, here we explore what is variously described as the dependent, ideal, continuous, position form:

$$CO = CO_{bias} + Kc \cdot e(t) + \frac{Kc}{Ti}\int e(t)dt$$

Where:

CO = controller output signal (the wire out)

CO_{bias} = controller bias or null value; set by bumpless transfer as explained below

e(t) = current controller error, defined as SP – PV

SP = set point

PV = measured process variable (the wire in)

Kc = controller gain, a tuning parameter

Ti = reset time, a tuning parameter

The first two terms to the right of the equal sign are identical to the P-Only controller referenced at the top of this article. The integral mode of the controller is the last term of the equation. Its function is to integrate or continually sum the controller error, e(t), over time. Some things we should know about the reset time tuning parameter, Ti: It provides a separate weight to the integral term so the influence of integral action can be independently adjusted. It is in the denominator so smaller values provide a larger weight to (i.e. increase the influence of) the integral term. It has units of time so it is always positive.

IV. RESULTS

Fig : Speed Control using PI

V. CONCLUSION

Any changes in the input voltage the output voltage of buck power converter is designed and as well as motor input current also reduced. According to the experimental results the main purpose of this paper was successfully achieved. The obtained results have shown that any variation in speed and torque the voltage cannot be varied. The performance evaluation can be done based on the comparison between conventional and proposed simulation results. The peak overshoot can be minimized by proposed system (PI). The peak overshoot in proposed PI system can be minimized to some extent. So that oscillation in speed can be limited. It is important to underline that these types of abrupt variations do not happen in practice at the same time, or such large variations regarding their nominal values. So that any change in supply voltage, torque variations or load changes buck power converter can limit the input voltage current and speed control is also possible by proposed simulink system.

REFERENCES

[1]. M. A. Ahmad, R.M. T. Raja Ismail, andM. S. Ramli, “Control strategy of buck converter driven DC motor: A comparative assessment,” Australian J. Basic Appl. Sci., vol. 4, no. 10, pp. 4893–4903, 2010.

[2]. F. Antritter, P. Maurer, and J. Reger, “Flatness based control of a buckconverter driven DC motor,” in Proc. 4th IFAC Symp. Mechatron. Syst., Heidelberg, Germany, Sep. 12–14, 2006, pp. 36–41.

[3]. S. E. Lyshevski, Electromechanical Systems, Electric Machines, and Applied Mechatronics. Boca Raton, FL, USA: CRC Press, 1999.

[4]. J. Linares-Flores and H. Sira-Ram´ırez, “A smooth starter for a DC machine: A flatness based approach,” in Proc. 1st Int. Conf. Electr. Electron. Eng., Acapulco, Mexico, Sep. 8–10, 2004, pp. 589–594.

[5]. J. Linares-Flores and H. Sira-Ram´ırez, “Sliding mode-delta modulation GPI control of a DC motor through a buck converter,” in Proc. 2nd IFAC Symp. Syst., Struct. Control, Oaxaca, Mexico, Dec. 8–10, 2004, pp. 405– 409.

[6]. J. Linares-Flores and H. Sira-Ram´ırez,“DCmotor velocity control through aDC-to-DC power converter,” in Proc. IEEE 43rd Conf.Decision Control, Atlantis, The Bahamas, Dec. 14–17, 2004, vol. 5, pp. 5297–5302.

[7]. R.Ortega, A. Loria, P. J. Nicklasson, andH. Sira-Ram´ırez,Passivity-Based Control of Euler-Lagrange Systems. London, U.K.: Springer-Verlag, 1998.

[8]. J. Linares-Flores, “Control suave de velocidad de motores de CD mediante convertidores de potencia CD/CD,” Ph.D. dissertation, Secci´on de Mecatr´onica del Departamento de Ingenier´ıa El´ectrica del CINVESTAVIPN, Mexico City, Mexico, 2006. J. Linares-Flores, A. Orantes-MolinayA. Antonio-Garc´ıa, “Arranque suave para un motor de CD a trav´es de un convertidor reductor CD-CD,” Ing. Investigaci´on Tecnol., vol. 12, no. 2, pp. 137–148, Oct. 2011.

[9]. H. El Fadil and F. Giri, “Accounting of DC-DC power converter dynamics in DC motor velocity adaptive control,” in Proc. IEEE Int. Conf. Control Appl., Munich, Germany, Oct. 4–6, 2006, pp. 3157–3162.

[10]. R. Sureshkumar and S. Ganeshkumar, “Comparative study of proportional integral and backstepping controller for buck converter,” in Proc. Int. Conf. Emerging Trends Electr. Comput. Technol., Tamil Nadu, India, Mar. 23–24, 2011, pp. 375–379.

[11]. O. Bing¨ol and S. Pac¸aci, “A virtual laboratory for neural network controlled DC motors based on a DC-DC buck converter,” Int. J. Eng. Educ., vol. 28, no. 3, pp. 713–723, 2012.