An Experimental Prototype of Buck Converter Fed Series DC Motor Implementing Speed and Current Controls

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Abstract— **This paper implements a speed/current control of a prototype series DC motor using a buck converter model. It first came up with, a performance analysis for current and speed controllers are provided followed by a simulation in MATLAB. Analyzing the discontinuous conduction mode (DCM) of the buck converter along with the non-linear behavior of the mechanical load put us forward to an efficient strategy for the linearization of speed ramp from stall to nominal speed. The strategy uses a neural network training routine to provide a practical modeling on a variety of converter's non-linear effects. Then, the whole procedure as a pre-design simulation study is practically implemented. The use of an AVR-controlled buck converter paves the way to a straightforward combined speed/current control. Meanwhile, it is shown that the constructed set avoids unnecessary complicated control system while preserving a very fast and desirable response.**

Keywords—**Battery; electric machine; power converter.**

I. INTRODUCTION

DC motors could efficiently be driven by PWM signals to control the motor input voltage. However, there are some serious problems exist such as underlying non-linear switching/load behavior. This may cause an unsatisfactory dynamic behavior or exhibit a very noisy shape [1]. Therefore, various combinations of dc-dc power converters with dc motors have been reported in a considerable amount of literature [2-8].

The buck type switched dc-dc converter is well known and organized in power electronics. Considering the converter's energy storing elements, a coil and a capacitor, smooth dc output voltages and currents can be generated [9]; however, the control system design of the converter is of an extreme importance in order to tackle with the non-linearity due to load/switching dynamic behavior.

In this paper, a strategy, in view of practical simplicity, is implemented to provide a somehow fast and accurate control over non-linear effects of load/switching dynamics. The strategy is based on training a neural network (NN) using recorded sample data. Also, this paper serves as an implementation report for the speed/current control of a prototype series DC motor. The whole procedure demonstrates pre-design simulation studies as well as a complete practical implementation.

II. SERIES DC MOTOR BASIC PRINCIPLES

The series DC motor provides high starting torque and is able to move very large shaft loads when it is first energized. Since the series field winding is connected in series with the armature, it will carry the same amount of current that passes through the armature. For this reason the field is made from heavy-gauge wire that is large enough to carry the load.

Every DC motor primarily described by the following equations:

$$E = K.\omega \;; \quad \tau_e = K.I_a \;; \quad K = L_{af}.I_f \tag{1}$$

where, ω is the shaft speed, I_a is the armature current, L_{af} is the mutual inductance between armature and stator.

The speed of a DC motor can be varied by controlling the field flux, the armature resistance or the terminal voltage applied to the armature circuit. The three most common speed control methods are field resistance control, armature voltage control, and armature resistance control. Here we use an armature voltage control to manage speed and current; as observed from the following equation.

$$\omega = \frac{V_{dc}}{\sqrt{L_{af}}} \times \frac{1}{\sqrt{\tau}} - \frac{R_a + R_f}{L_{af}} \tag{2}$$

In the other hand, the use an inductor could be waived when considering the DC motor windings inductance. Besides, the inner induced voltage of the DC motor operates identical to an output capacitor voltage. Therefore, a diode and an IGBT form a buck converter (Fig. 1); used to control the motor's input infeed. Meanwhile, practically speaking, it is impossible to precisely determine/measure the parameters, *R* and *L*, to put into control equations. Therefore, the control loop uses instantaneous values of current, voltage and speed, as the only solution.

III. BUCK CONVERTER

The buck converter, as shown in Fig. 1, comprises a set of diode and switch along with a low-pass LC filter. Using a proper duty cycle control over the switches, it is possible to control the output voltage. Here, as mentioned in section II, we need only a diode and a switch to implement a complete buck converter operation.

As it is obvious from basic power electronics, operation of buck converter may be in either continuous conduction mode (CCM) or discontinuous conduction mode (DCM). Whether the operation of buck converter is in CCM or in DCM depends upon the load resistance R_l, motor's inductance L, pulse duration D, and switching frequency $1/T_s$. Generally speaking, the converter enters DCM when the inductor's current reaches zero; otherwise, the converter remains in CCM. According to [9], $\frac{2L}{RT_s} > (1-D)$ determines the CCM margin. It should be mentioned that only in CCM the converter's gain is linear and equals to $V_0 = DV_i$. The DCM gives the non-linear gain of

$$\frac{2}{1+\sqrt{1+\frac{4k}{D^2}}}, \qquad k=\frac{2L}{RT_s}$$

On the other hand, we may increase the switching frequency in order to guarantee the CCM operation. However, some D's cause DCM operation mainly due to the variability of the load resistance.

IV. Speed and Current Control

As a rule of thumb in control theory, measuring the speed/current is necessary to control it. Here, we use a discrete PI controller; measured speed/current is compared to its reference giving an error signal. This error is fed to the PI loop; then, the controller's output provides pulse durations ready to be fed into the switch. The PI's output is adjusted automatically

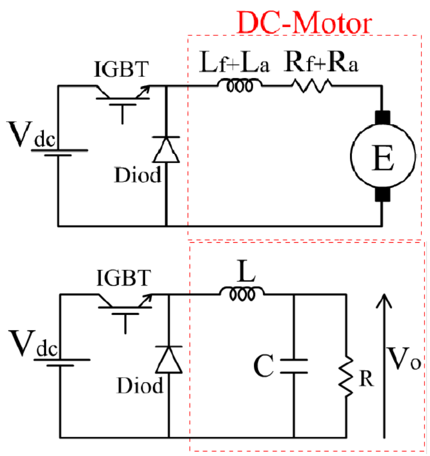


Figure 1. The buck converter used to supply a DC motor.

till the input error approaches zero. The simulation result for speed is presented in Fig. 3 which is obtained from the simulation diagram of Fig. 2.

V. Implementation

As mentioned in the introduction, the main purpose of this paper is to implement a robust while simple controller for a series DC motor. Therefore, a test set was designed with the following specifications:

Series DC motor: 24V, 600W

Mechanical load: fan

Switch: IGBT 60A, 1200V, *Driver*: Skyper32

Diode: 100A, 1200V

Sensor: Hall Effect, 200A; Autonics, BMS300-DDT

Processor: ATMEGA 64, #2

Supply: Battery, 12V, 75Ah, #2

One of the processors is for measuring speed/current samples and another is for implementing the PI controller along with generating pulse wide modulation. There is also an interface board sending recorded samples to computer. The test set is shown in Fig. 4. Speed sensor is a IR one. The operation of this sensor is illustrated by Fig.5.

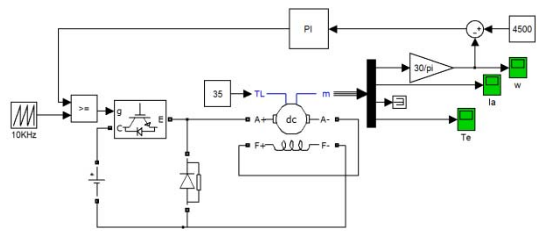


Figure 2. Schematic diagram of simulation set.

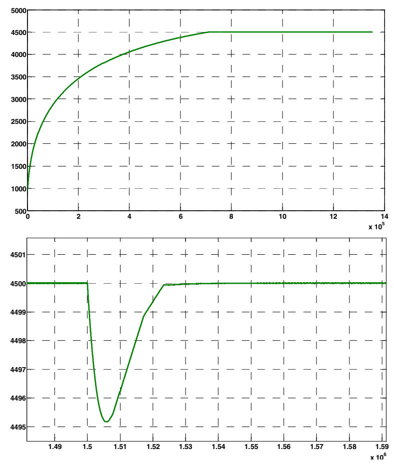


Figure 3. Speed controller simulation.

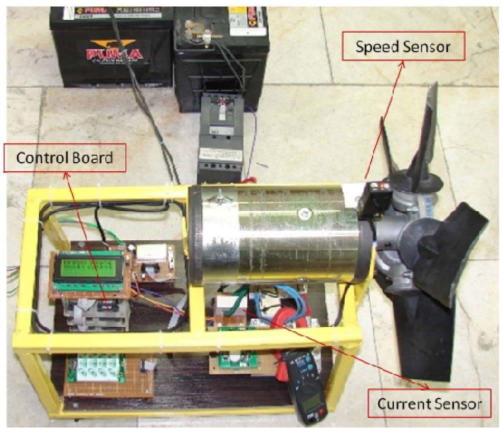


Figure 4. Experimental set

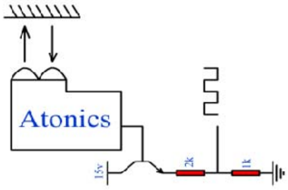


Figure 5. Used speed sensor.

This type of speed sensing seriously suffers from noise effects due to several factors such as motor vibration and environmental impacts. A 5:1 averaging technique is employed here to reduce noise effects. One possible problem occurs when there is a noise with high amplitude. In such a condition, the controller will operates to retain the normal operation of the motor (see Fig. 6).

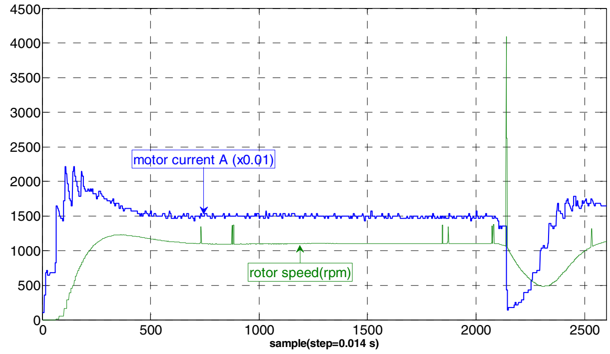


Figure 6. Suppresion of the effect of a high-amplitude noise.

Figure 7 shows the PI controller performance for tracking a speed reference. It is also shown in Fig. 8 the mode of operation for current tracking. Dynamic operation of the controller during speed/current control mode is illustrated in Figs. 9(a)-(b).

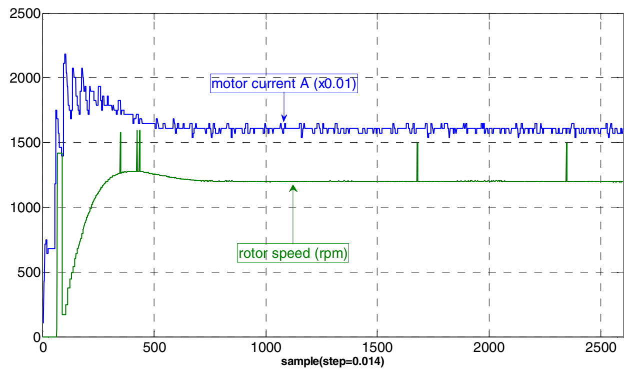


Figure 7: Motor speed/curmet in speed control mode.

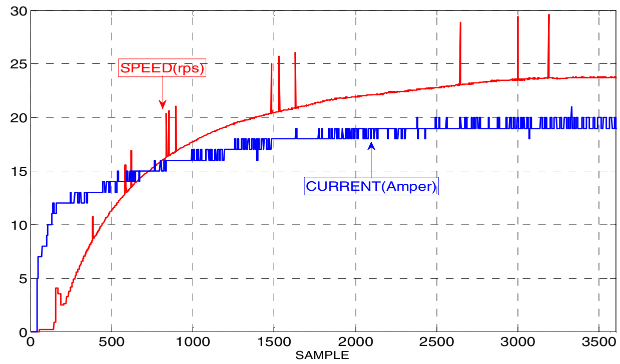
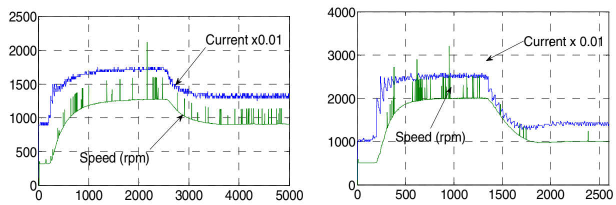


Figure 8. Motor speed/curmet in current control mode.



(a) (b)

Figure. 9. Dynamic response of the controller, (a) current control mode, (b) speed control mode.

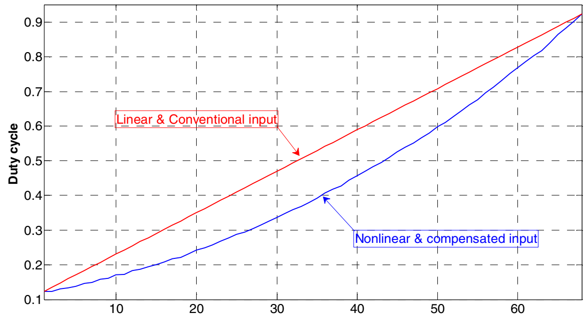


Figure. 10. Two types of trace for *D*.

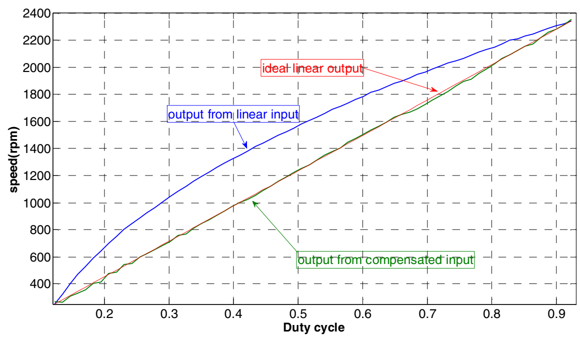


Figure. 11. Two types of speed regulation.

A. Speed Linearization

When the D changes between 0.123 to 0.925 linearly (see Fig. 10, red curve), the speed go through a non-linear path (see Fig. 11, blue curve). To compensate this non-linear overcome, we propose using a NN to calculate an input such that it can linearise the speed. The training of this NN has been done using recorded samples. The result is illustrated in Fig. 10, blue curve along with Fig. 10, green curve. As obvious from these figures, the result is satisfactory.

VI. CONCLUSION

It has been presented in this paper, a brief implementation report and some techniques to linearly control the speed for a series DC motor driving a blower. The emphasis is on a simple but efficient experimental set that provides a linear speed/current control using a trained NN. Any extension is possible on this set and is a potential background for future work.

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