Design and Implementation of a Digital PID Controller for DC–DC Buck Converter

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***Abstract*—This paper presents the design, simulation and real-time implementation of a digital PID controller for DC-DC buck converter. The developed controller is capable to drive the output voltage of the buck converter to track a desired voltage reference regardless of input voltage or load variations. The parameters of the digital PID controller are calculated based on the transfer function of the buck converter and Matlab PIDTOOl. An Arduino Uno is used to implement the developed controller. Numerical simulation and experimental validation are presented to demonstrate the effectiveness of the developed controller in terms of overshoot limitations and accuracy.**

***Index Terms*—Arduino Uno, DC-DC buck converter, Digital PID controller.**

I. Introduction

DC-DC converters perform two functions: change the output voltage level (increase or decrease) and provide a constant load voltage. There are different topologies of DC-DC converters, among theme, we can cite the buck converter which is used often to step-down voltage from its input to its load. Many industrial applications use this kind of converters (battery chargers, computers, medical devices...) due to their high efficiency, low cost, reduced size. However, the control of theses converters are still a difficult task because such a system exhibits a nonlinear model, and disturbances and uncertainties [1]- [8].

Recently, many control techniques for DC-DC buck converter has been proposed such as linearization control [9], [10], backstepping control [11], adaptive control [12], sliding mode [13], fuzzy logic control [14], [15] and fuzzy Takagi-Sugeno models based control [8]. Among all these techniques, the PID control still the most commonly used technique due to its easy practical implementation and low cost [16]- [19].

The main contribution of this paper is the design, simulation and real-time implementation of a new PID controller for a buck converter using an Arduino Uno and Matlab/Simulink environment. Firstly, the mathematical model of the buck converter is presented. Secondly, the continuous-time PID controller and its digital form are developed. Next, simulation and experimental tests are presented to show the effectiveness of the developed controller in terms of time responses, overshoot limitations and accuracy. Finally, the paper is ended by conclusion.

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II. Modelling of DC-DC buck converter

The DC-DC buck converter circuit is shown in Fig.1 which is consists of a DC power supply V_i, $MOSFET$ transistor, output capacitor C, inductor L, ultrafast diode D, and resistor load R.

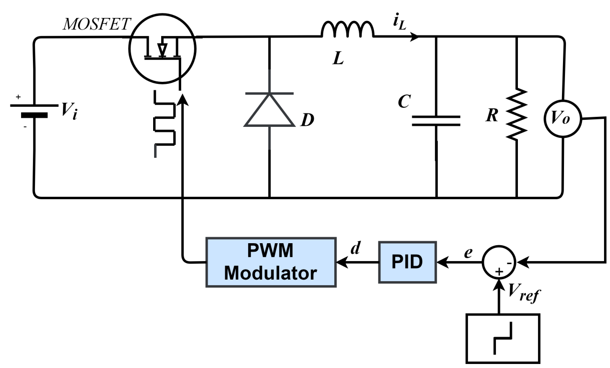


Fig. 1. Overall control scheme.

The transfer function of a DC-DC buck converter is given by [20]:

$$G(s) = \frac{V_o}{u} = V_{in}\left(\frac{R}{R+R_L}\right)\left(\frac{\frac{s}{\omega_{ZERO}}+1}{\Omega(s)}\right) \quad (1)$$

where

$$\Omega(s) = \frac{s^2}{\omega_0^2} + \frac{s}{Q\omega_0} + 1$$

TABLE I
PARAMETERS OF THE BUCK CONVERTER

Parameters	Value
Output capacitor C	$270\ uF$
MOSFET resistance R_m	$0.1\ \Omega$
Output capacitor resistance R_c	$0.18\ \Omega$
Inductor L	$600\ uH$
Winding resistance of inductor R_L	$0.1\ \Omega$
Resistance load R	$30\ \Omega$
Switching frequency f_s	$31.38\ KHz$

$$\omega_0 = \frac{1}{\sqrt{LC\dfrac{R+R_c}{R+R_L}}}, \quad \omega_{ZERO} = \frac{1}{CR_c}$$

$$Q = \frac{1}{\omega_0\left(\dfrac{L}{R+R_L} + \dfrac{RR_LC}{R+R_L} + R_cC\right)}$$

The considered buck converter components are shown in Table I.

III. DIGITAL PID STRUCTURE

The famous temporal expression of a pid controller is given by:

$$u(t) = K_pe(t) + K_i\int_0^{\tau} e(\tau)d\tau + K_d\frac{de(t)}{dt} \tag{2}$$

where $u(t)$ denotes the control signal and $e(t)$ denotes the error. K_d represents the derivative gain, K_p represents proportional gain and K_i represents the integral gain.

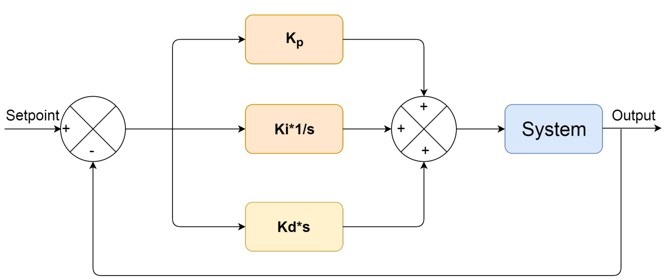


Fig. 2. Parallel PID controller form diagram

The discrete-time PID-controller form can be given by:

$$u_k = K_pe_k + K_i\sum_{n=1}^{k} e_k + K_d(e_k - e_{k-1}) \tag{3}$$

The implementation of discrete-time PID-controller is provided by using the following known velocity form:

$$u_k = u_{k-1} + K_p(e_k - e_{k-1}) + K_ie_k + K_d(e_k - 2e_{k-1} + e_{k-2}) \tag{4}$$

IV. NUMERICAL SIMULATION AND EXPERIMENTAL VALIDATION

A. Numerical simulation

In order to show the validity and effectiveness of the developed controller, numerical simulation tests are established using the the overall scheme presented in Figure 3 for a step signal $V_{ref} = 6V$ where the input voltage is set to be $V_{ref} = 12V$. Figure 5(a) to Figure 5(d) show, respectively, the responses of the output voltage, error, duty cycle and PWM signal. It is clear from these simulation results that the voltage load follow perfectly its reference voltage with a very short time response $(0.15s)$ and without overshoot.

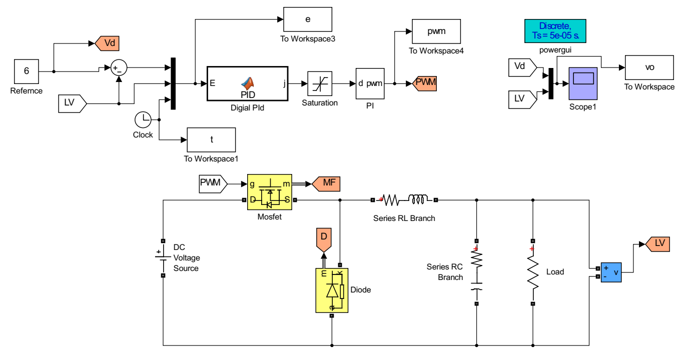


Fig. 3. Simulink model control

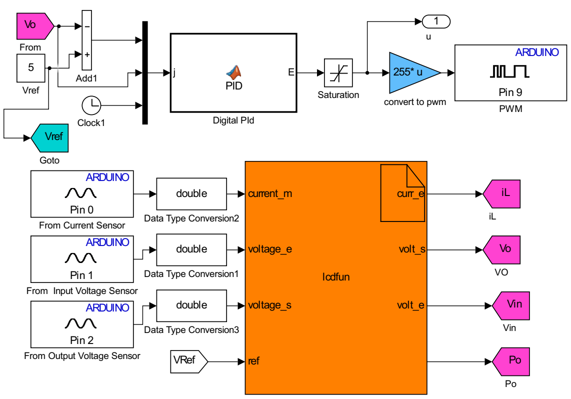
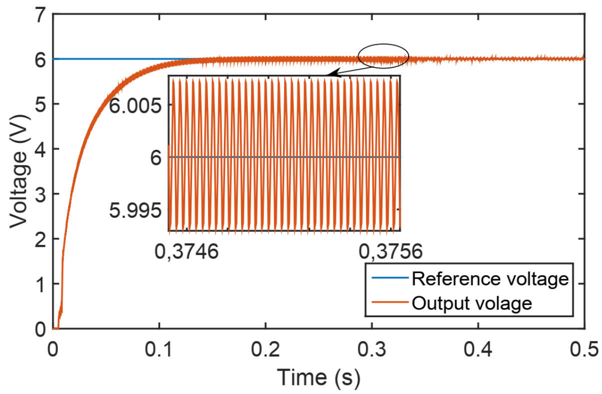


Fig. 4. Simulink model for hardware implementation.

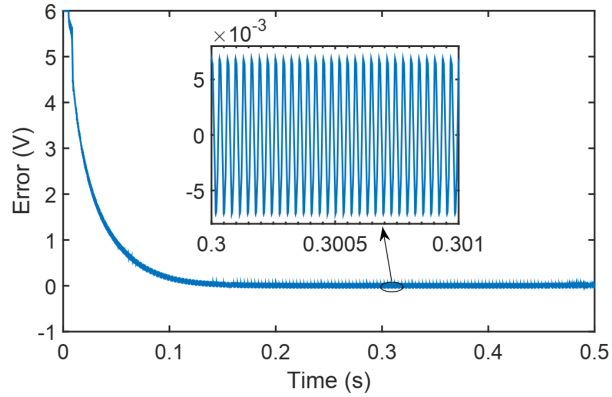
V. EXPERIMENTAL RESULTS

In order to verify the simulation results, experimental tests are carried out using the Matlab/Simulink environment and an Arduino Uno. As shown in Figure 4, a spatial Simulink arduino package is employed to interface the Matlab software with the hardware. The test bench consists of DC-DC buck converter, a current sensor, a voltage current sensor, a computer equipped with MATLAB/Simulink platform, DC power supply, PC USB oscilloscope and an Arduino uno, as shown in Figure 6.

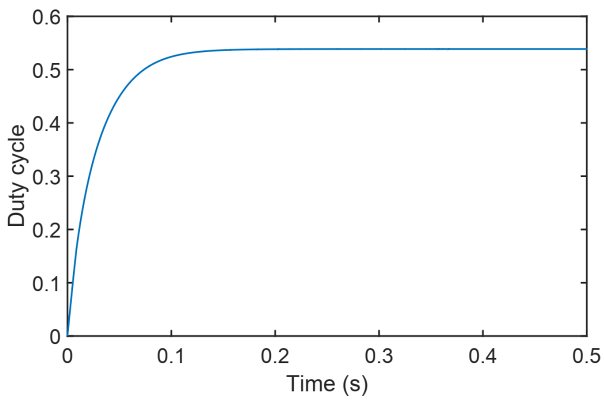
The experiment is performed with an input voltage $V_{in} = 10V$. Figure 7 show the experimental responses of the duty



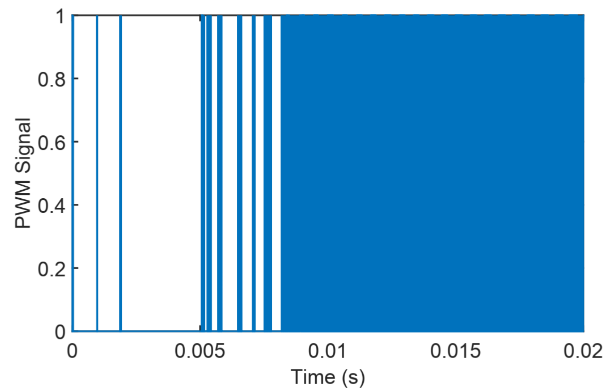
(a) Output voltage.



(b) error



(c) Duty ratio.



(d) PWM signal.

Fig. 5. Simulation results for voltage reference $V_{ref} = 6V$.

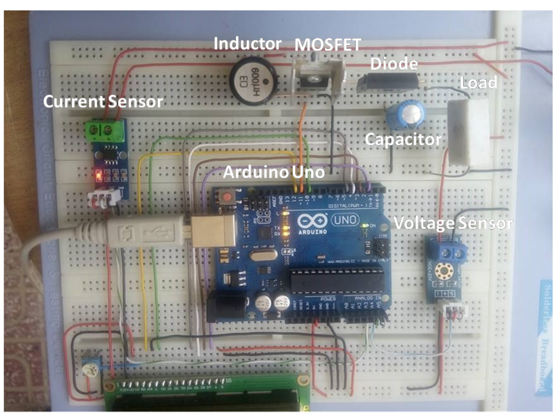


Fig. 6. Hardware setup.

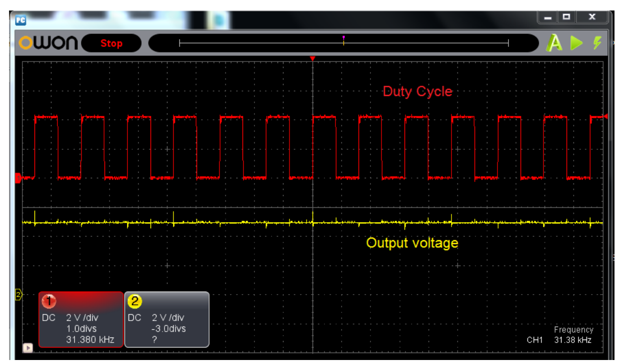


Fig. 7. Experimental waveforms for desired voltage $V_{ref} = 5V$.

cycle and output voltage for reference voltage $V_{ref} = 5V$ and Figure 8 show the experimental response of output voltage for multi-step voltage. It is clear from these experimental results that the voltage load tracks perfectly its reference voltage with a very short time response and without overshoot.

VI. Conclusion

In this work, the design and real-time implementation of a PID controller for buck converter using an Arduino uno and Matlab/Simulink environment is proposed. The developed controller is qualified to drive the output voltage to follow a reference voltage signal. The presented numerical simulation tests and experimental results show the effectiveness of the developed controller in terms of overshoot limitations and accuracy.

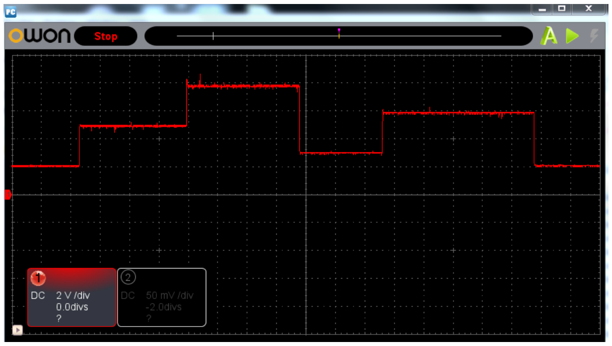


Fig. 8. Experimental waveforms for multi-step reference voltage $V_{ref} = 12V$.

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