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PREFACE

The contemporary development of a society requires increased productivity and production quality in all fields of industry. In electrical and mechanical engineering as well as information technology this is most obvious in basic production processes and other engineering activities. In the last decades, new techniques and technologies have seen intensive advance and their application in production systems has also been increasing.

Contemporary production is nowadays computer integrated by applying software that enables simultaneous product and manufacturing process design and complete CAD/CAPP/CAM integration of design and production.

These accomplishments, present in the developed countries, are within reach and can be acquired by intensifying our education, scientific research and development efforts, which include presenting the most important results of the past few years at this Conference.

The DEMI conference is a major meeting for presentation of new research and development results in electrical and mechanical engineering as well as information technology. The aim of the DEMI 2015 Conference is to present scientific and professional accomplishments and possibilities for their application, but also to set course for future research and development, in order to improve manufacturing aspects of industry by introducing new technologies.

The Conference includes the following thematic fields:

- Production and Computer-Aided Technologies
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- Mechanics and Design
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- Maintenance of Engineering Systems and Occupational Safety Engineering

117 papers will be presented at the Conference. The fact that there are 89 papers submitted from abroad reflects the international character of the Conference.

The DEMI 2015 Conference is an opportunity for researchers and engineers, both from the academic community and industry, to get together, to exchange experiences and to define the state of affairs in the industry as well as to create preconditions for the development of new capacities and ambient for new investments.

The Ministry of Science and Technology of the Republic of Srpska has supported the organization of this Conference, thus contributing to the improvement of scientific-research and development activities in the field of electrical and mechanical engineering as well as information technology for which the organizer of the Conference is very grateful.

On behalf of the Organizing Committee of the Conference, we would like to express our gratitude to all domestic and foreign authors as well as to the members of referee teams for their reviews.

In Banja Luka, 20 May 2015

Chairman of the Organizing Committee
Prof. Vid Jovišević, PhD

University of Banja Luka
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THE ADVANTAGE OF USING DIGITAL QUASI-SLIDING MODE IN COMPARISON WITH ANALOGUE PID SLIDING MODE CONTROLLER

Muhanad D. Almawlawe[1], Darko Mitic[2] , Marko Milojkovic[3]

Summary: *This paper presents a comparative analysis of two techniques for controlling DC-DC buck converters: the analogue technique that is based on the proportional-integral-derivative (PID) sliding mode (SM) voltage control, and the digital one using quasi-sliding mode based generalized minimum variance (QSMGMV) control. Both converters provide good voltage regulation and exhibiting robustness to parameter and load variations. The voltage regulation in the converter with QSMGMV controller is achieved by measuring only the sensed output voltage, whereas with PID SM controller, the use of current sensor is mandatory. The former convertor has also smaller output voltage ripple in comparison with the latter one. On the other hand, the acceptable performance in the converter with PID SM control is reached by tuning only three controller parameters in familiar way.*

Key words: DC-DC buck converter, continuous conduction mode (CCM), proportional-integral-derivative controller (PID), sliding mode (SM) voltage controller, pulse width modulator (PWM).

1. INTRODUCTION

DC –DC converters are power electronic circuits that convert a dc voltage to a different voltage level. They have a very large presence in all kind of electronic circuits, from industrial to personal applications due to their efficiency and reliable operation. There are different types of conversion method such as electronic, linear, switched mode (as presented in this paper), magnetic, and capacitive, as well as different converter topologies (buck, boost, buck-boost).

In this paper, we consider the buck (step-down) converter that produces a lower output voltage than the DC input voltage [1, 2]. As DC-DC converters are nonlinear and time variant systems, the linear control techniques are not suitable, so in order to achieve a robust output voltage, sliding mode (SM) controllers are implemented. SM control is a class of variable structure control [3], providing robust system motion along a predefined

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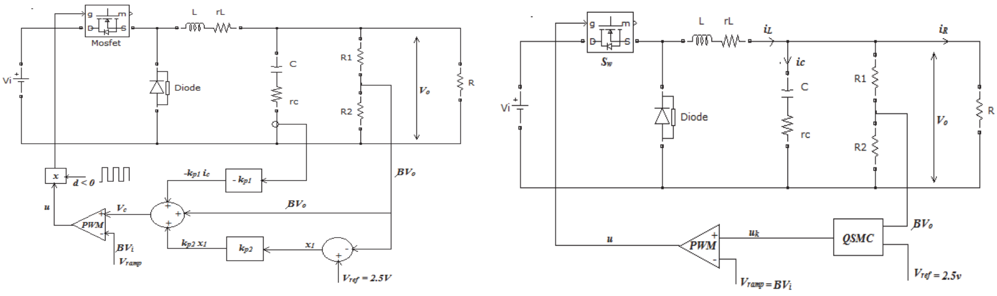
sliding surface. It is insensitive to system parameter uncertainty and external disturbances under certain conditions, and is suitable for power converting systems.

SM controllers operate at very high switching frequency and, therefore, produce an excessive switching, inductor and transformer core losses, as well as electromagnetic interference (EMI) noise issues. Hence, their switching frequencies must be constricted within a practical range [4], with using PWM technique to overcome this problem.

The paper deals with the comparative analysis of two DC-DC buck converters. The first one is with a continuous-time proportional-integral-derivative (PID) SM controller [5], and the second one uses digital quasi-sliding mode based generalized minimum variance (QSMGMV) control [6]. The advantages of the latter approach over the former one is that it demands measuring only the converter output voltage, as well as it can be easily implemented with standard microcontrollers.

2. CONTROL DESIGN PROCEDURES

In this section, the brief descriptions of design procedures for converters with both SM controllers are given. They are explained at large in [5] and [6] for PID SM and quasi-sliding mode based minimum variance control, respectively. The schemes of converters are depicted in Fig. 1.



(a) (b)

Fig.1 *Buck converters with* (a) *PID SM and (b) QSMGMV controllers*

2.1 PID SM Controlled Buck Converter

The continuous-time state-space model of DC-DC buck converter can be derived from Fig. 1 (a) in the following form [5]:

$$\dot{\mathbf{x}}_{buck} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & \frac{1}{RC} & 0 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ -\frac{\beta V_i}{RC} \\ 0 \end{bmatrix} u \, , \tag{1}$$

where x_1, x_2 and x_3 denote a voltage error, a voltage error rate, and an integral of voltage error determined by:

$$
\begin{aligned}
\mathbf{x}_{buck} &= \begin{bmatrix} x_1 & x_2 & x_3 \end{bmatrix} = \begin{bmatrix} V_{ref} - \beta V_o & \dfrac{d\left(V_{ref} - \beta V_o\right)}{dx} & \int\left(V_{ref} - \beta V_o\right) dt \end{bmatrix} = \\
&= \begin{bmatrix} V_{ref} - \beta V_o & \dfrac{\beta V_o}{RL} + \int \dfrac{\beta\left(V_o - V_i u\right)}{LC} dt & \int\left(V_{ref} - \beta V_o\right) dt \end{bmatrix}.
\end{aligned}
\tag{2}
$$

Let us define the switching function of SM control [5] by:

$$
s = c_1 x_1 + c_2 x_2 + c_3 x_3 \tag{3}
$$

Note that *s*=0 denotes a equation of sliding surface. Now, we can calculate the control signal V_c as an equivalent control from $\dot{s} = 0$, taking into account (1) and (3):

$$
V_c = u_{eq} = -\beta L\left(\frac{c_1}{c_2} - \frac{1}{RC}\right) i_c + LC\left(\frac{c_3}{c_2}\right)\left(V_{ref} - \beta V_o\right) + \beta V_o\,, \tag{4}
$$

and mapped it onto PWM duty cycle function *d*:

$$
0 < d = \frac{V_c}{V_{ramp}} < 1\,, \tag{5}
$$

where $V_{ramp} = \beta V_o$ is a PWM ramp signal.

2.2 QSMGMV Controlled Buck Converter

The transfer function of DC-DC buck converter can be obtained from Fig. 1 (b) as:

$$
W_{buck}(s) = \frac{Y(s)}{U(s)} = \frac{\dfrac{\beta V_i}{LC}}{s^2 + \dfrac{1}{R_L C} s + \dfrac{1}{LC}}\,, \tag{6}
$$

where $Y(s) = \beta V_o(s)$. Under the assumption that control signal is a constant during the sampling period *T*, $u(t)=u(kT)$, $kT < t < (k+1)T$, the input-output model of DC-DC Buck converter in *z*-domain can be represented by:

$$
y(k) = \frac{z^{-1}B(z^{-1})}{A(z^{-1})}u(k),\ A(z^{-1}) = a_0 + a_1 z^{-1} + a_2 z^{-2},\ B(z^{-1}) = b_0 + b_1 z^{-1}, \tag{7}
$$

where z^{-1} is an unit delay and:

$$
\begin{aligned}
&a_0 = 1,\ a_1 = -2e^{-aT}\cos\omega_0 T,\ a_2 = e^{-2aT},\ b_0 = \frac{k}{a^2 + \omega_0^2}\left(1 - e^{-aT}\cos\omega_0 T\right), \\
&b_1 = \frac{k}{a^2 + \omega_0^2}\left(e^{-2aT} - e^{-aT}\cos\omega_0 T\right),\ k = \frac{\beta V_i}{LC},\ a = \frac{1}{2R_L C},\ \omega_0 = \sqrt{\frac{1}{LC} - \frac{1}{4R_L^2 C^2}}.
\end{aligned}
\tag{8}
$$

Under an assumption that the reference input signal in subsequent time instants ($V_r(k+1)$, $V_r(k+2)$,…) is known in advance and equal to V_{ref}, QSMGMV control law for the DC-DC buck converter is defined as [7]:

$$u(k) = -\frac{F(z^{-1})y(k) - C(z^{-1})V_r(k+1) + \dfrac{\alpha T}{1-z^{-1}}\operatorname{sgn}(s(k))}{E(z^{-1})B(z^{-1}) + Q(z^{-1})}. \tag{9}$$

$s(k)$ represents the switching function given by:

$$s(k) = C(z^{-1})(y(k) - V_r(k)) + Q(z^{-1})u(k-1), \tag{10}$$

and:

$$C(z^{-1}) = c_0 + c_1 z^{-1} + c_2 z^{-2},\ Q(z^{-1}) = q(1 - z^{-1}). \tag{11}$$

$C(z^{-1})$ is a polynomial with all zeroes inside the unit disk in z-plane, while the polynomial $Q(z^{-1})$ must satisfy $Q(1)=0$ The polynomials $E(z^{-1})$ and $F(z^{-1})$ are the solutions of so called Diophantine equation:

$$C(z^{-1}) = E(z^{-1})A(z^{-1}) + z^{-1}F(z^{-1}), \tag{12}$$

with

$$E(z^{-1}) = e_0 = c_0 / a_0,\ F(z^{-1}) = f_0 + f_1 z^{-1},\ f_0 = c_1 - e_o a_1,\ f_1 = c_2 - e_0 a_2. \tag{13}$$

Notice that $s(k)=0$ is an equation of sliding hyper-surface. Based on (7), (9), (10) and (12), we get the switching function dynamics in the following form:

$$s(k+1) = s(k) - \alpha T \operatorname{sgn}(s(k)). \tag{14}$$

If $\alpha > 0$, a quasi-sliding motion is established in Δ-vicinity of $s(k) = 0$, i.e. $|s(k)| \le \Delta$ is always satisfied, where Δ is a function of αT. Then, the system overall stability depends on the roots of equation:

$$B(z^{-1})C(z^{-1}) + A(z^{-1})Q(z^{-1}) = 0, \tag{15}$$

which have to be inside the unit disk in the z-plane. In that way, the main aim of design to maintain the sensed output voltage $y(k)=\beta V_O(k)$ stable, constant and equal to some, reference voltage $V_r(k)=V_{ref}$, despite the variations of load resistance R, is achieved.

3. SIMULATION RESULTS

The comparative analysis of the proposed control algorithms is performed by using digital simulation results. The values of buck converter components, used in simulations, are given in Table 1.

The coefficients of PID SM controller are $\beta L\left(c_1 / c_2 - 1/(RC)\right) = 26.1753$ and $LC\left(c_3 / c_2\right) = 5.9218 \cdot 10^3$. The parameters of QSMGMV controller are chosen as follows: $C(z^{-1}) = 1 - 1.067z^{-1} + 0.2846z^{-2}$ $Q(z^{-1}) = 0.0001 \cdot (1 - z^{-1})$, T=50 μs, $\alpha = 1$, $E(z^{-1}) = 1$, $F(z^{-1}) = 0.9289\text{-}0.7129z^{-1}$. For both controllers PWM frequency is 200 kHz and $\beta = 0.208$.

The time responses of converter output voltages and current with PID SM and QSMGMV controllers are presented in Fig. 2 and Fig. 3, respectively. The simulations show a smaller ripple of the output voltage with QSMGMV control than it is case with the implementation of PID SM controller, as well as good voltage regulation. However, PID SM control algorithm provides smoother output voltage. The settling time of converter with PID SM control is about 0.016 s, whereas with QSMGMV controller is twice faster and equal to 0.008 s.

Table 1 *Buck converter component values*

Description	Parameter	Nominal Value
Input Voltage	V_i	24v
Capacitance	C	1500µF
Capacitor resistance	r_c	21e-3Ω
Inductance	L	1000µH
Inductor resistor	r_L	0.12Ω
Switching Frequency	f_s	200KHz
Load Resistance	R	3Ω
Expected Output Voltage	Vo	12v

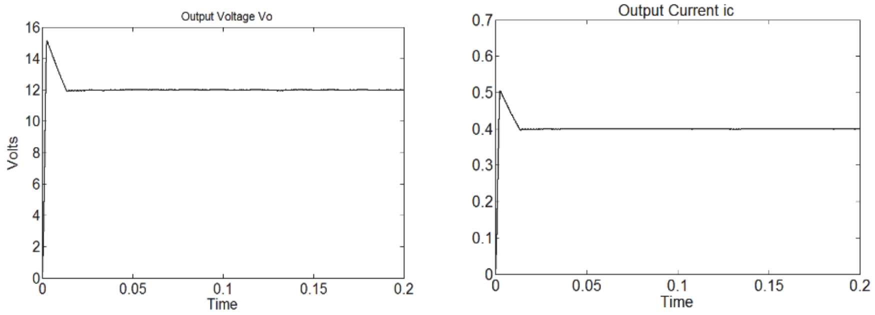


Fig. 2 *Output voltage and current of buck converter with PID SM control*

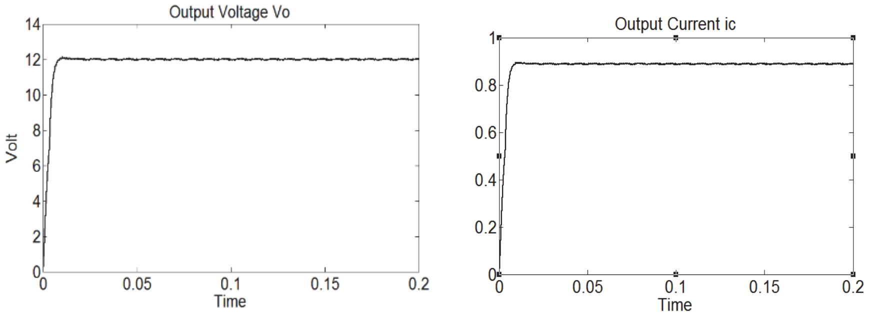


Fig. 3 *Output voltage and current* i_c *of buck converter with QSMMV control*

4. CONCLUSION

Two control techniques for DC-DC buck converter are considered in this paper: the continuous-time PID sliding mode (SM) control, as well as digital quasi-sliding mode based generalized minimum variance (QSMGMV) control law. QSMGMV control needs only measuring of output voltage signal in order to ensure robust performances of the converter. On the other side, it is necessary to use the current sensors in the implementation of PID SM controller. Although the realization of QSMGMV is much easier thanks to nowadays microcontrollers, the calculation of PID SM controller parameters is simpler and more straightforward. The settling time of converter is twice faster with QSMGMV controller than in the case when PID SM control law is applied.

REFERENCES

[1] Erickson, R. W., Maksimovic, D. (2000). *Fundamentals of power electronics*. Second edition, Kluwer Academic Publishers. ISBN 0-7923-7270-0.

[2] Bengt. Johansson. (2004). *DC-DC Converters Dynamic Model Design and Experimental Verification*. ph. D. Disertation, Lund University, Department of Industrial electrical Engineering and Automation.

[3] V. Utkin, J. Guldner, and J. X. Shi. (1999). *Sliding Mode Control in Electromechanical Systems*. London, UK: Taylor and Francis.

[4] P. Mattavelli, L. Rossetto, G. Spiazzi, and P. Tenti, (*1993).* General-Purpose Sliding-Mode Controller for DC-DC Converter Applications. *IEEE Power Electronics Specialists Conf. Rec. (PESC), pp. 609–615.*

[5] S. C. Tan, Y. M. Lai, C. K. Tse, and M. K. H. Cheung, Nov. (2005). A Fixed-Frequency Pulse-width-Modulation Based Quasi Sliding Mode Controller for Buck Converters. *IEEE Trans. Power Electron.,* vol. 20*,* no.6*,* pp.1379–1392.

[6] D. Mitic, D. Antic, M. Milojković, S. Nikolić, S. Perić (2012). Input-Output Based Quasi-Sliding Mode Control of DC-DC Converter. *Facta Universities*, Ser: Elec. Energ., vol. 25, no. 1, pp. 69-80.

[7] D. Mitić (2006). *Digital Variable Structure Systems Based On Input-Output Model.* Ph. D. Disertation, University of Niš, Faculty of Electronic Engineering.