

# Simulation of Deadbeat Controlled Buck Converter

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**Abstract**—Deadbeat control (DBC) provides to have the output voltage of Direct Current - Direct Current (DC-DC) converters access to a specific reference value and then to have this reference value be followed up a periodically without any steady state errors. Buck converters are used in the systems for which output voltage is requested to be lower than the input voltage. These converters are usually used in military industries and robot technologies. In this study; Matlab/Simulink, the polynomial toolbox software and buck converters are used. First of all, buck converters are designed and build. Secondly the DBC method is applied to buck converters. According to result faster responding buck converter is obtained under the two different load conditions.

**Index Terms**—deadbeat control (DBC), buck converter, matlab/simulink, the polynomial toolbox software

## I. INTRODUCTION

Buck converters are power electronics circuits that use one or more switches in order to convert the voltage from one level to the other. Output voltage of buck converter is adjusted by changing the duty cycle of periods. In this method, also called as Pulse Width Modulation (PWM) switching, the working ratio of the switch (D) is changed. Switching period determines the quality of the voltage. The more high switching frequency the more quality of the output voltage will be so good.

Various control techniques are used in the control of buck converters. Deadbeat Control (DBC) technique is one of them and will be used when a fast or finite localization-time control is requested Ref. [1]. Although DBC technique is only used in digital control systems, it has advantages listed here

- 1) DBC compared to other control methods within a short period of time can control the system.
- 2) DBC provides a very fast transient response. It compensates the bad effects of load and the effects of non-linear loads.
- 3) Steady-state error is zero.
- 4) It has a minimum rise time.

5) Minimum settling time.

6) Transcendence is less than 2%.

There are a lot of studies in literature DBC Ref. [2], [3]. One of them, Ref. [2] is applied to constrained deadbeat control for multi-input systems. The authors explain in their study that DBC can be defined as the determination of a control sequence, so that the control process can be taken from the initial state  $x_0$  to a desired state  $x_1$  in a minimum number of time steps. As it is obvious from this description, DBC problem can also be represented as the discrete time optimal control problem.

The other literature, [3] is applied to DSP controlled power converter. The authors explain that the DSP controller is designed in three approaches: a) Discretization of analog controller b) Digital PID controller design c) Deadbeat controller design.

The features of the polynomial toolbox are determined in the other literature [4]. Deadbeat transfer function used for controlling buck converter is obtained the polynomial toolbox and Matlab software.

Minimum L and C are used for buck converters is determined in the other literature [5-7]. This minimum value is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply.

The transfer function of buck converter is obtained in other literature [8-10]. The buck converter's small signal control-to-output transfer function, is derived the standard state-space averaging technique.

Design of deadbeat control is explained in the literature [11].

In this study, different from previous we designed and applied to buck converter by using Matlab/Simulink and the polynomial toolbox software.

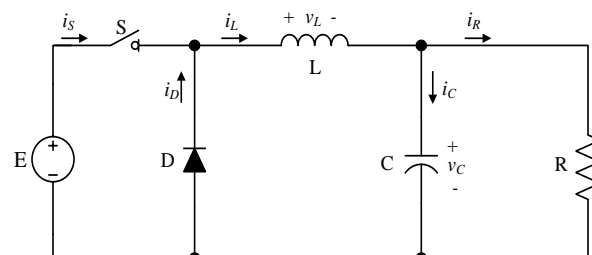


Figure 1. Buck converter

## II. DEADBEAT CONTROL OF BUCK CONVERTER

### A. Buck Converter

In Fig. 1 it is given a circuit of buck converter. S switching element (IGBT, MOSFET vb.) performs the switching process at high frequencies and the power flow of the system is provided.

The relationship between the average output voltage in buck converters ( $V_o=V_c$ ) and  $D$  is given in (1) as;

$$\frac{V_o}{E} = \frac{t_{on}}{T} = D \quad (1)$$

where  $V_o$  is the average output voltage of the system,  $E$  is the voltage value at the input of the buck converter,  $t_{on}$  is the period of the switching-on,  $T$  is the switching period and  $D$  is the duty cycle. As seen in the equation; if the switch is continuously kept at transfer status, i.e. if the  $t_{on}$  period is equal to the switching period  $T$ , duration will be 1 and the output voltage will be equal to the input voltage.  $t_{on}$  lower than  $T$ , for all situations;  $V_o$  will be lower than the  $E$ . Thus the voltage applied to the converter input is transferred to the output by reduction.

### B. The Polynomial Toolbox

The Polynomial Toolbox, as discussed in Ref. [4], is a toolbox for use with Matlab for polynomials and polynomial matrices and their application in systems, signals and control. The toolbox can also solve various linear and quadratic polynomial matrix equations, analyze and design control systems and filters by polynomial methods and solve classical, optimal and robust design problems. It provides a Simulink block set for Linear Time Invariant (LTI) systems described by polynomial matrix fractions and supports conversion to and from LTI systems described by polynomial matrix fractions. Its features are specified below.

- 1) Over 200 Matlab code files for polynomials and polynomial matrices
- 2) Consists of objects, overloaded operations, functions, equation solvers, gui and graphics
- 3) New generation of numerical algorithms
- 4) System and signal models based on polynomial matrix fractions
- 5) Analysis and design tools for control and filters
- 6) Classical, optimal and robust design

### C. Design and Transfer Function of the Buck Converter

In this study, two different types of buck converters are used. For the buck converter circuit to be used; the minimum values of the inductor and the capacitor should be specified Ref. [5]. We know the fact that the buck converter can either operate in its continuous conduction mode or discontinuous mode. When it operates in the continuous conduction mode, there is always a current in the inductor. The minimum current in the continuous conduction mode can be zero. Consequently, there is a minimum value of the inductor that ensures its continuous conduction mode. Thus;

$$L = \left(\frac{TR}{2}\right)(1-D) \quad (2)$$

$$\Delta I_L = \left(\frac{E-V_c}{L}\right)DT \quad (3)$$

$$C = \left[\frac{\Delta I_L T}{8\Delta V_c}\right] \quad (4)$$

Equations are used. Where,  $C$  is the output capacitance,  $L$  is the inductance, and  $R$  is the load resistance,  $\Delta V_c$  is capacitor voltage ripple and  $\Delta I_L$  is inductance current ripple.

As an example; as described in detail in Ref. [6], [7] the label values in Table I are used in order to calculate the minimum  $L$  and  $C$  values for buck converter-1. These calculations are performed for the buck converter-2 and shown in Table I.

$$L = \left(\frac{TR}{2}\right)(1-D) = \left(\frac{0,0000025 \cdot 2,5}{2}\right)(1-0.416) = 0,000001825H$$

$L=1,825 \mu H$  is found.

$$I_{max} - I_{min} = \left(\frac{E-V_c}{L}\right)DT = \left(\frac{12-5}{0,000001825}\right) \cdot 0,416 \cdot 0,0000025 = 3,989A$$

$$C = \left[\frac{(I_{L,max} - I_{L,min})(T)}{8\Delta V_c}\right]$$

$$C = \left[\frac{(I_{max} - I_{min})(T)}{8 \cdot 0,1}\right] = \left[\frac{3,989 \cdot 0,0000025}{0,8}\right]$$

$C = 12,46 \cdot 10^{-6} F$  then  $C=12,46 \mu F$ .

As described in detail in Ref. [8], [9], [10] the buck converter's small signal control to output transfer function, derived by the standard state-space averaging technique, is given by (5).

$$G_p(s) = \frac{\hat{v}_o(s)}{\hat{d}(s)} = \frac{V_o}{D} \frac{1+sR_c C}{1+s \left[ R_c C + \left( \left( \frac{R R_L}{R+R_L} \right) C + \frac{L}{R+R_L} \right) \right] + s^2 LC \left( \frac{R+R_c}{R+R_L} \right)} \quad (5)$$

where  $V_o$  is the output voltage,  $\hat{v}_o(s)$  and  $\hat{d}(s)$  are the small variations of the output voltage and duty cycle, respectively.  $D$  is the duty cycle,  $C$  is the output capacitance,  $L$  is the inductance, and  $R$  is the load resistance.  $R_c$  and  $R_L$  are the equivalent series resistance (ESR) of  $C$  and  $L$ .

Substituting the values of the buck converter-1 for  $V_o = 5V$ ,  $D = 0.416$ ,  $C = 470 \mu F$ ,  $L = 12 \mu H$ ,  $R = 2.5 \Omega$ ,  $R_c = 120m\Omega$  and  $R_L = 37.5m\Omega$ .

The control to output transfer function of buck converter-1 becomes

$$G_p(s) = \frac{67,68 \cdot 10^{-5} s + 12}{5,8233 \cdot 10^{-9} s^2 + 7,8494 \cdot 10^{-5} s + 1} \quad (6)$$

Substituting values of buck converter-2 for  $V_o = 5V$ ,  $D = 0.416$ ,  $C = 376 \mu F$ ,  $L = 4.1 \mu H$ ,  $R = 1 \Omega$ ,  $R_c = 5m\Omega$ ,  $R_L = 80m\Omega$ .

The control to output transfer function of buck converter-2 becomes

$$G_p(s) = \frac{22,56 \cdot 10^{-6} s + 12}{1,4345 \cdot 10^{-9} s^2 + 33,5263 \cdot 10^{-6} s + 1} \quad (7)$$

TABLE I. VALUES, TRANSFER FUNCTION, DISCRETE TRANSFER FUNCTION, DEADBEAT TRANSFER FUNCTION AND CHARACTERISTIC EQUATION OF THE BUCK CONVERTER-1 AND BUCK CONVERTER-2

Parameters	Buck converter - 1	Buck converter - 2
E[V]	12	12
V <sub>o</sub> [V]	5	5
R <sub>load</sub> [Ω]	2,5	1
C [F]	0,00047	0,000376
L[H]	0,000012	0,0000041
R <sub>i</sub> [Ω]	0,0375	0,08
R <sub>c</sub> [Ω]	0,12	0,005
D	0,416	0,416
T[sn]	0,0000025	0,00001
ΔV <sub>c</sub>	0,1	0,1
G <sub>p</sub> (s)	$\frac{67,68 \cdot 10^{-3} s + 12}{5,8233 \cdot 10^{-9} s^2 + 7,8494 \cdot 10^{-3} s + 1}$	$\frac{22,56 \cdot 10^{-6} s + 12}{1,4345 \cdot 10^{-9} s^2 + 33,5263 \cdot 10^{-6} s + 1}$
G <sub>p</sub> (z)	$\frac{1,183z - 0,9901}{z^2 - 1,858z + 0,8739}$	$\frac{0,5239z - 0,2177}{z^2 - 1,73z + 0,7916}$
D(z)	$\frac{-23z + 26}{z + 29}$	$\frac{3,5z - 0,45}{z - 0,12}$
C.E.	z <sup>3</sup>	z <sup>3</sup>

D. Discretization of the Buck Converter System

In order to perform the DBC of the buck converter; the system should be discretized. A continuous system is made as discrete by the Z conversion. The transfer function of the discrete system is found as follows.

$$G_p(z) = \left(\frac{1-z^{-1}}{z}\right) Z\left[\frac{G(s)}{s}\right] \quad (8)$$

Discrete transfer function of buck converter-1 is obtained by substituting (6) in (8)

$$G_p(z) = \frac{1,183z - 0,9901}{z^2 - 1,858z + 0,8739} \quad (9).$$

Discrete transfer function of buck converter-2 is obtained by substituting (7) in (8)

$$G_p(z) = \frac{0,5239z - 0,2177}{z^2 - 1,73z + 0,7916} \quad (10).$$

E. Design of Deadbeat Control

Typical controlled buck converter is represented by the block diagram shown in Fig. 2. In Fig. 2, the A/D converter converts continuous output signal V<sub>out</sub>(T) to digital form which is readable for controller. When the controller receives a data, it processes the data and generates variable duty cycle D (kT). As the output of the buck converter is controlled by the duty cycle.

As described in detail in Ref. [11], Fig. 3 shows the block diagram of digital control systems in which all the components are subject to only digital data. Fig. 3 illustrates the design principle of a deadbeat response controller for digital control systems. Where the transfer function of a digital process is G<sub>p</sub>(z), the transfer function of cascade digital controller is D(z). The open-

loop transfer function of the system becomes G(z) = D(z)G<sub>p</sub>(z). The closed-loop transfer function is

$$M(z) = \frac{C(z)}{R(z)} = \frac{G(z)}{1 + G(z)}.$$

DBC transfer function of buck converter-1 is obtained by the polynomial toolbox and Matlab software.

$$D(z) = \frac{-23z + 26}{z + 29} \quad (11)$$

DBC transfer function of buck converter-2 is obtained by the polynomial toolbox and Matlab software.

$$D(z) = \frac{3,5z - 0,45}{z - 0,12} \quad (12)$$

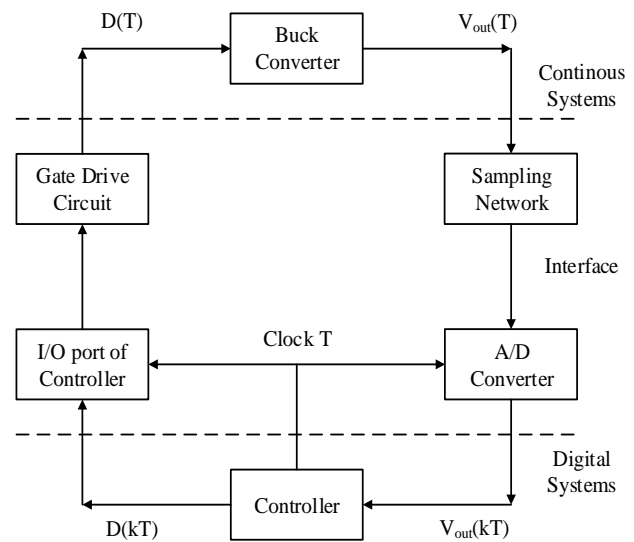


Figure 2. Block diagram of controlled buck converter

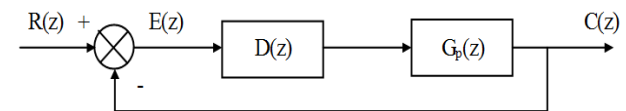


Figure 3. An all-digital control systems

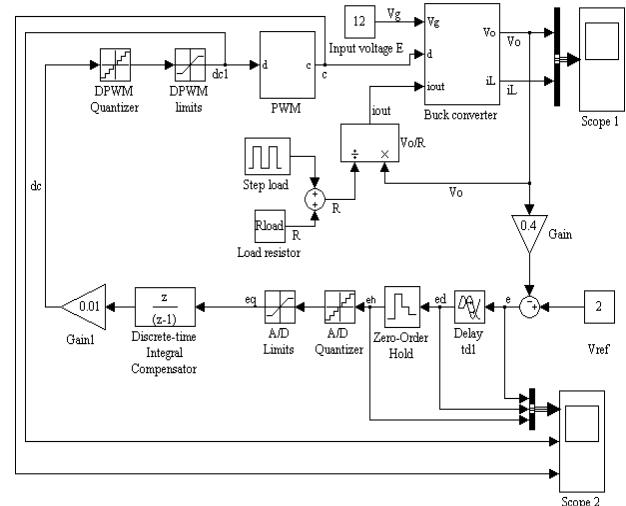


Figure 4. Digital closed-loop control of buck converter-1, 2

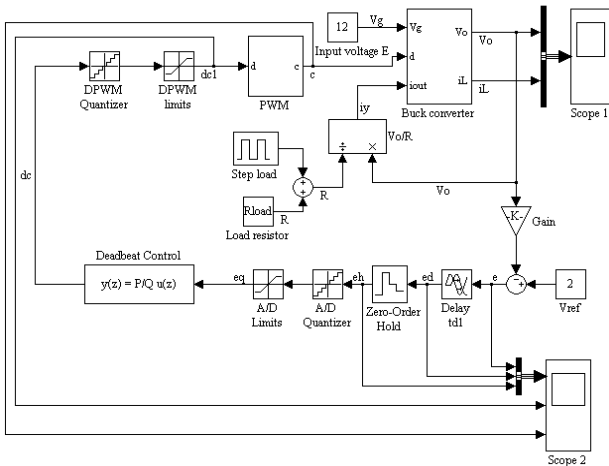


Figure 5. Digital closed-loop DBC of buck converter-1, 2

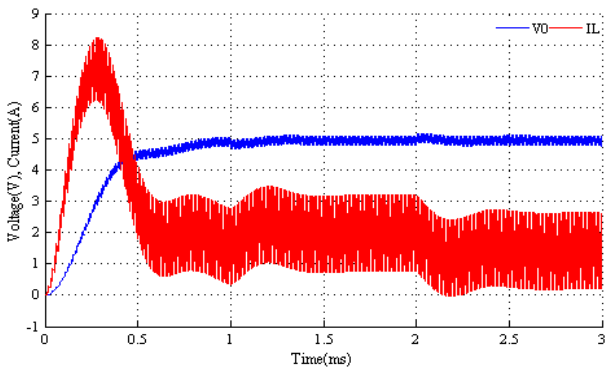


Figure 6. Output voltage and inductor circuit of the closed loop numerical control of buck converter-1

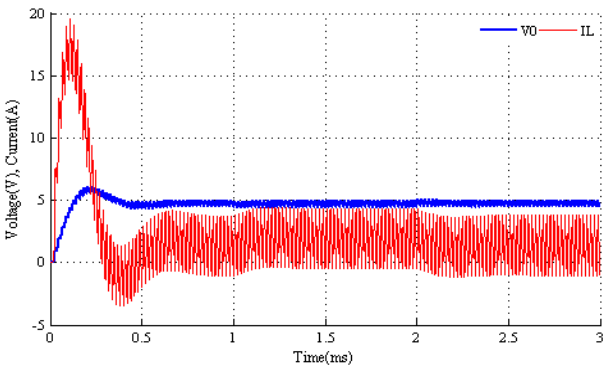


Figure 7. Output voltage and inductor circuit of the closed loop DBC of buck converter-1

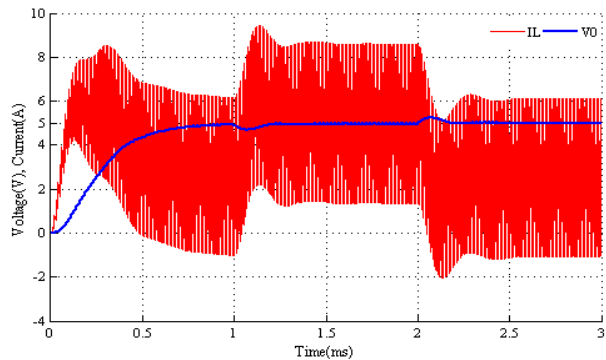


Figure 8. Output voltage and inductor circuit of the closed loop numerical control of buck converter-2

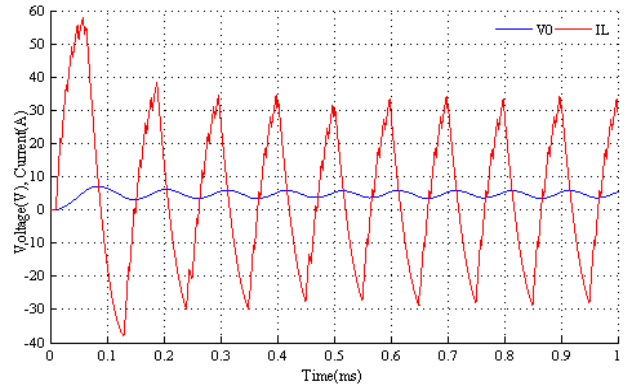


Figure 9. Output voltage and inductor circuit of the closed loop DBC of buck converter-2

### III. SIMULATION RESULTS

Simulation results regarding to the deadbeat controlled buck converters are given above. Simulink model and simulation results of the digital DBC and the digital integral control of buck converter-1, 2 are seen in Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8 and Fig. 9. In Fig. 6, Fig. 7, Fig. 8 and Fig. 9; it can be seen that the digital deadbeat controlled buck converter output voltage reaches reference voltage value faster than the digital integral controlled buck converter output voltage. This situation shows the superiority of the DBC technique.

### IV. CONCLUSION

In this study, DBC technique is applied to the buck converters by using the Matlab, Simulink and The Polynomial Toolbox software. First of all, buck converters are designed and build. Secondly the DBC method is applied to buck converters. The closed loop digital integral control of the buck converters and the simulation of the closed loop digital DBC are performed by the Matlab/Simulink program and the results are compared. Fast responding buck converters are obtained with the deadbeat controller. These devices are used in the military industry and in robot technologies. Regarding to deadbeat control, insufficient studies are performed in the world and in our country. This study will contribute to the studies about DBC.

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