Sigma J Eng & Nat Sci 8 (2), 2017, 91-97

Publications Prepared for the Innovations on Intelligents Systems and Applications Symposium ASYU 2016
Akıllı Sistemler ve Uygulamalardaki Yenilikler Sempozyumu ASYU 2016 için Hazırlanan Yayınlar

**Research Article / Araştırma Makalesi**

# MODEL PREDICTIVE CONTROL OF A DC-DC BUCK CONVERTER

**Yahya DANAYİYEN*[1], İsmail Hakkı ALTAŞ[1], Erdinç ŞAHİN[2]**

[1]*Karadeniz Technical University, Department of Electrical and Electronics Engineering, TRABZON*
[2]*Karadeniz Technical University, Surmene Abdullah Kanca VHO, TRABZON*

**Received/Geliş: 02.12.2016 Accepted/Kabul: 11.12.2016**

**ABSTRACT**

DC-DC converters are highly considered in recent years because of the increased use of the renewable energy sources (RES). Since the energy output of the RES is depended on the weather conditions, DC-DC converters are used to regulate variable RES output. In this study, simulation based model predictive control (MPC) of a DC-DC buck converter is carried out. The performance of the designed controller is investigated under variable load condition and results are compared with PID controller. The transfer function of the converter model is used to design MPC controller in MATLAB/Simulink. MPC gives the better solution when it compared to PID controller under condition of constant load. The overshoot is not occurred when the predictive controller is used. PID provides better solution under the condition of load change whereas the overshoot is increased.
**Keywords:** Model predictive control, buck converter, feedback control.

## 1. INTRODUCTION

DC-DC buck converter circuits include both linear and nonlinear parts. Switching devices make its structure nonlinear. A digital signal which is triggering signal of the semiconductor switches is used as an input signal of the system. The input and output voltage and current of buck converter should be in a specific interval as such in the other power electronics converters [1]. These constraints should be taken into account in the controller design. The system constraints and nonlinear parts are easily introduced the design in MPC method. This control method gives desired system response when it is used in a buck converter [2]. MPC is a control method which calculates the future values of the system behaviour using an accurate system model with predetermined criteria in the objective function. The system model should be as close as the real system and system mathematics should be well known to obtain a better MPC. A well-known system model makes the parameter estimation easy [3]. There are some studies in which different MPC approaches are used to control of a buck converter in the literature A nonlinear predictive control method approach has been applied in [4] for a buck converter. Robust predictive controller has been investigated in [5]. MPC method is applied to a buck converter including

* Corresponding Author/Sorumlu Yazar: e-mail/e-ileti: yahya@ktu.edu.tr, tel: (462) 377 20 86

nonlinear inductance and nonlinear capacitance in [6] and [7], respectively and fourth order buck topologies in [8].

In this study, the output voltage of a DC-DC buck converter is controlled by MPC method which is designed in MATLAB/Simulink environment. The system constraints are taken into account in the controller design process. The results are compared with PID controller. In the second section, brief descriptions of MPC and buck converter are given. Finally the simulation results are given in the third section.

## 2. MPC AND DC-DC BUCK CONVERTER

The general representation of a buck converter is shown in figure 1. MPC uses the output voltage and reference voltage as two inputs. The optimization procedure is carried out using a predefined criterion to calculate the optimal input sequence. The first term of this sequence is applied to PWM generator as an input. PWM generator produces optimal duty cycle ratio and apply it to switching element.

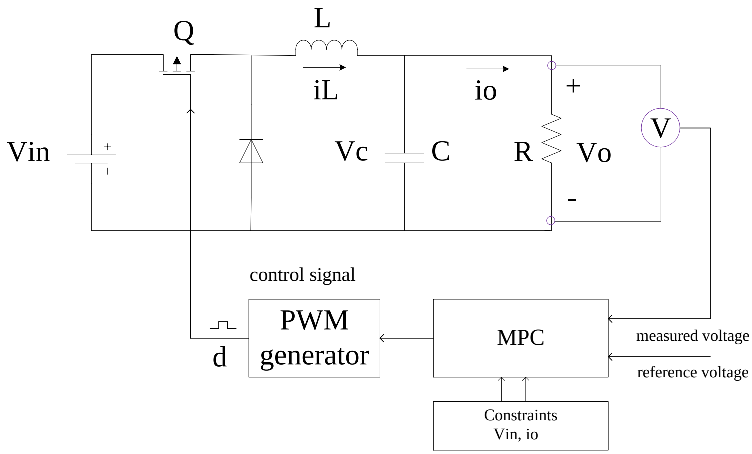


**Figure 1.** General block diagram of the system

### 2.1. Model Predictive Control

MPC method depends on an accurate system model. The future behaviour of the system is calculated with an optimization cost function based on receding horizon principle using current system values. The first element of the calculated input vector which is obtained every time step is applied to the system as a control input within a predefined optimization window. The basic principle of MPC is shown in figure 2. At the current time instant $k$, the calculated control sequence $\Delta U$ is given below [9]. The first element of $\Delta U$ is chosen as an input at time instant $k$.

$$\Delta U = [\Delta u(k) \quad \Delta u(k+1) \quad \Delta u(k+2) \quad . \quad . \quad . \quad \Delta u(k+N_c-1) \quad ]$$
$$u(k) = \Delta u(k) + u(k-1)$$

The discrete time model of a linear time invariant system is given in (1) and (2), respectively.

$$x(k+1) = Ax(k) + Bu(k-r) \tag{1}$$

$$y(k) = Cx(k) \tag{2}$$

The predicted state and output equations for the discrete time LTI system is given in (3) and (4), respectively.

$$\hat{x}\big((k+j|k)\big) = \hat{A}\hat{x}\big((k+j-1|k)\big) + \hat{B}\hat{u}((k+j-\hat{r}|k)) \tag{3}$$

$$\hat{y}\big((k+j|k)\big) = C\hat{x}\big((k+j|k)\big) \tag{4}$$

The cost function is given in (5). It is defined as a quadratic programming. $Q_w$ and $R_w$ are the weigth matrixes that should be chosen properly taken into account the system model. The objective function $J$ is calculated in every time step within the optimization window [9].

$$J = (R_s - Y)^T Q_w (R_s - Y) + \Delta U^T R_w \Delta U \tag{5}$$

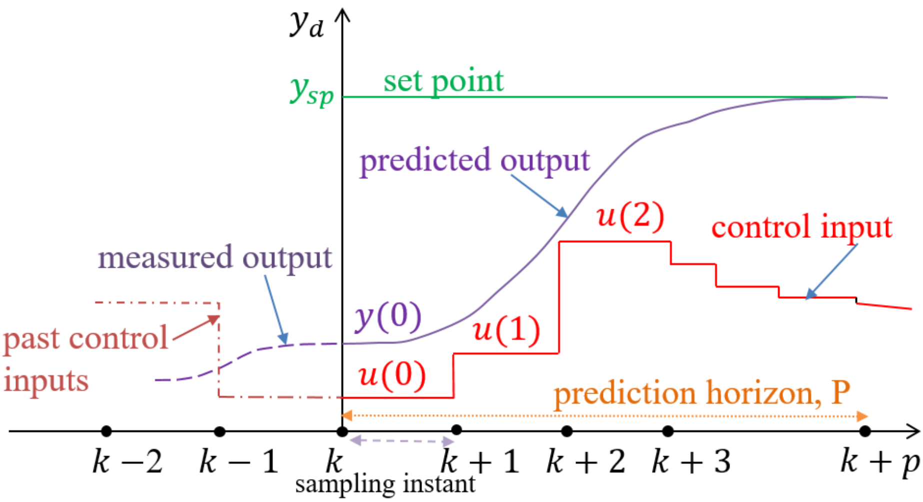


**Figure 2.** Basic principle of Model Predictive Control

**2.2. DC-DC Buck Converter**

A buck converter is a switch mode power electronic circuit which steps down input DC voltage to a lower value output DC voltage. Schematic of the proposed converter is given in Fig. 3. The converter consists of an inductor (L), output capacitor filter (C), switching element (Q), diode (D) and resistor (R) as a load.

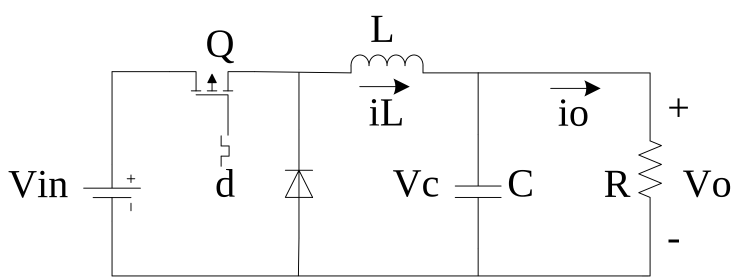


**Figure 3.** The circuit diagram of buck converter

Buck converter operates in two-state. The first state is the switch On-state and the other state is the switch Off-state. These states are briefly described in the following sections, respectively.

#### 2.2.1. Switch On-state

In this state, the diode is reverse biased and the inductor is charged by input voltage as seen in Fig. 4. The equations of this state is given in (6-10).

$$V_{in} = V_L + V_o \tag{6}$$

$$V_{in} = L\frac{di_L}{dt} + V_o \tag{7}$$

$$\frac{di_L}{dt} = \frac{V_{in}-V_o}{L} \tag{8}$$

$$V_o = V_c \qquad i_c = C\frac{dV_o}{dt} \tag{9}$$

$$\frac{dV_o}{dt} = \frac{1}{C}(i_L - \frac{V_o}{R}) \tag{10}$$

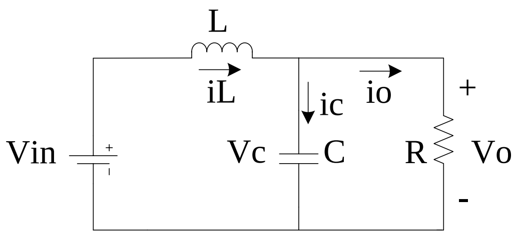


**Figure 4.** Switch On-state of a buck converter

#### 2.2.2. Switch OFF-state

In this state, the diode is forward biased. The charged inductor behaves as a current source and linearly discharged. The differential equations of this state is given in (11-12). The schematic of this state is also shown in Fig. 5.

$$\frac{di_L}{dt} = -\frac{V_o}{L} \tag{11}$$

$$\frac{dV_o}{dt} = \frac{1}{C}(\frac{i_L-V_o}{R}) \tag{12}$$

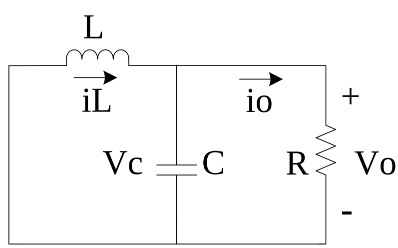


**Figure 5.** Switch OFF-state of a buck converter

The equations belong to aforementioned states are used to obtain average model of the converter. The average model equations are given below.

$$\dot{x}_1 = -\frac{1}{L}x_2 + \frac{d}{L}V_{in} \tag{13}$$

$$\dot{x}_2 = -\frac{1}{C}x_1 + \frac{1}{RC}x_2 \tag{14}$$

**Table 1.** The parameters of the converter

| Parameters | Symbol | Value |
|---|---|---|
| Load | $R$ | 20 Ω |
| Inductance | $L$ | 3.23mH |
| Capacitance | $C$ | 6300μF |
| Input voltage | $V_i$ | 10 V |
| Reference voltage | $V_r$ | 4 V |

## 3. SIMULATION RESULTS

MPC method is used to control output voltage of the buck converter in order to obtain desired output voltage without oscillations and fluctuations. The designed controllers are tested under variable load. The system constraints are taken into account. In Fig. 6, the results are obtained with the prediction horizon $N_P = 10$ and the control horizon is $N_C = 6$. For the tuning of PID parameters, trial-error method is used. There is no overshoot when the MPC is used and oscillation in the output signal is observed when PID is used as seen in Fig. 6. With the new parameters $N_P = 20$ and $N_C = 19$, the system response is showed in Fig. 7. The result is examined under condition of variable load and constant reference. PID gives better performance compared to MPC as seen in Fig. 8. Because MPC controller depends on accurate system model. The result is shown in Fig. 8.

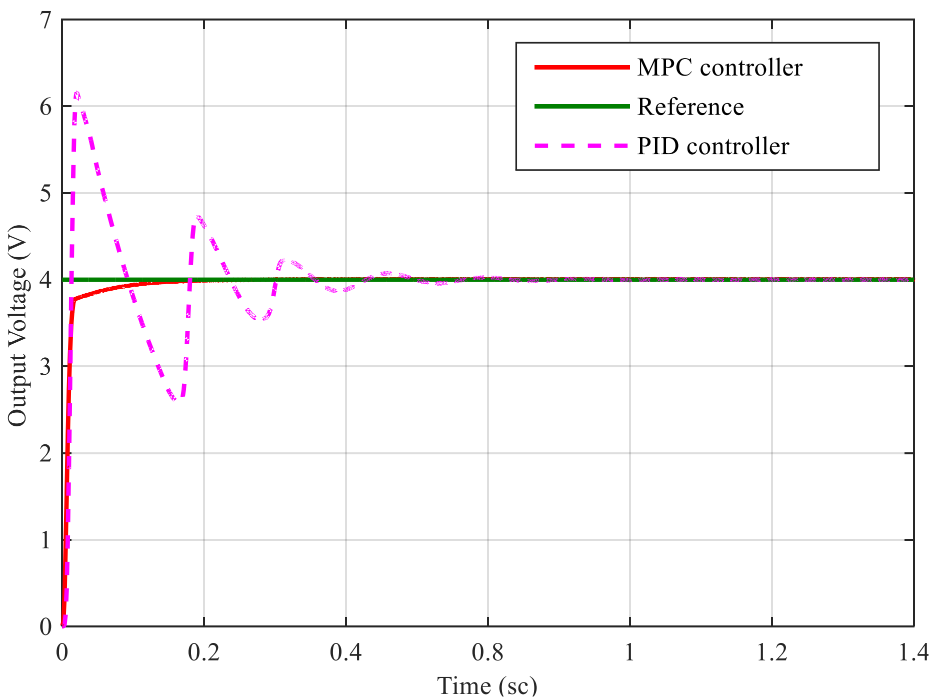


**Figure 6.** System results with MPC and PID controller: Np=10, Nc=6, Kp=0,Ki=20,Kd=0

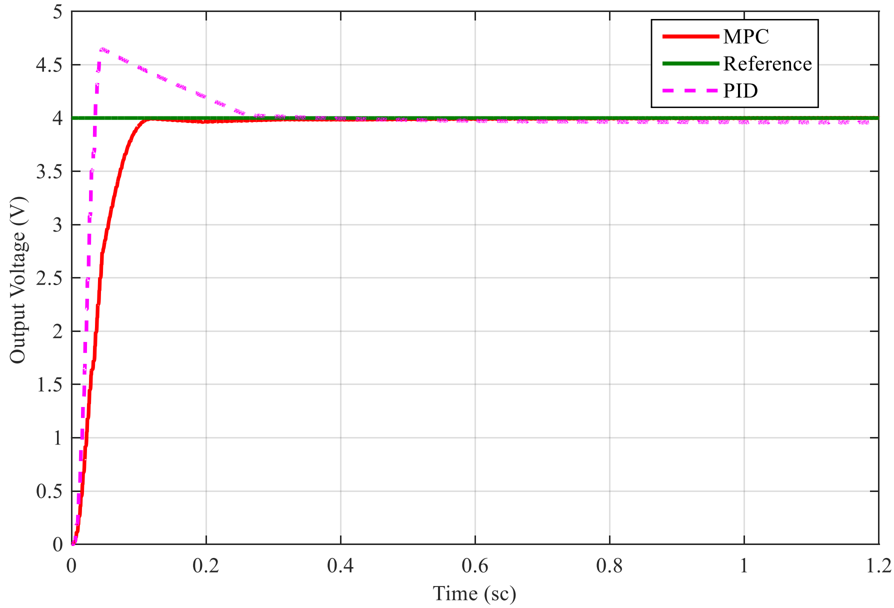


**Figure 7.** System results with MPC and PID controller: Np=20, Nc=19, Kp=10,Ki=20,Kd=0.1

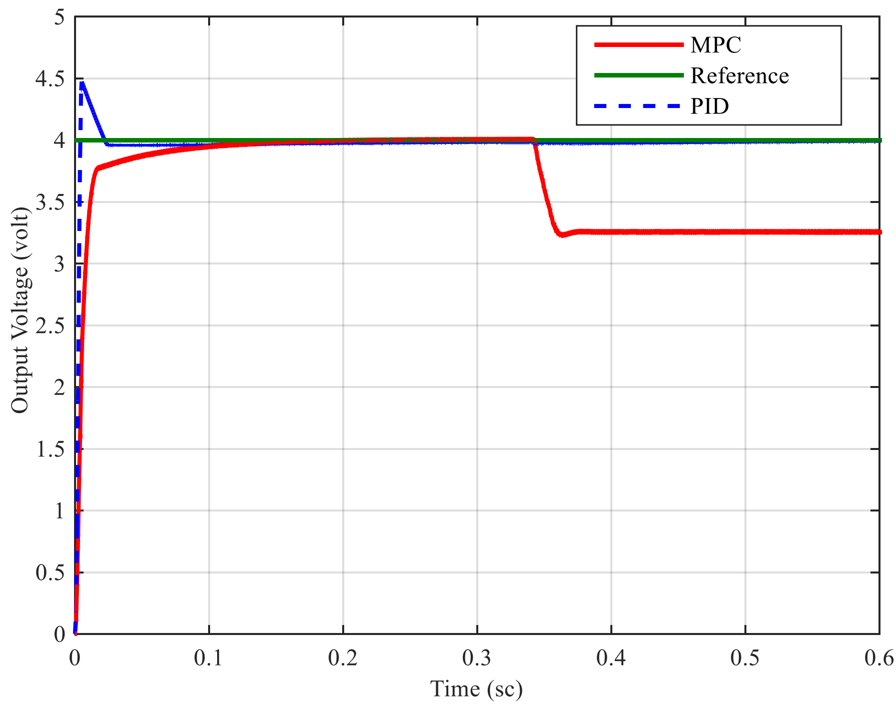


**Figure 8.** System results with MPC and PID controller under condition of variable load

## 3. CONCLUSION

The output voltage of a DC-DC buck converter is controlled by using MPC in this study. The controller is designed in MATLAB/Simulink and the constraints in the system such as voltage limitations are taken into account in the controller design process. The reference tracking of output voltage is aimed in the designed controller. The results are compared with PID controller and effectiveness of MPC is evaluated.

## REFERENCES / KAYNAKLAR

[1] M. P. Kumar, P. Ponnambalam, S. Sreejith, J. Belwinedward, and K. Krishnamurthy, (2014) Comparison of fuzzy and MPC based buck converter, 2014 IEEE Int. Conf. Power Electron. Drives Energy Syst. PEDES 2014,16-19 December 2014, Mumbai, India

[2] J. Rodriguez and P. Cortes, (2012) Predictive Control Of Power Converters And Electrical Drives, Wiley-IEEE.

[3] S. Di Cairano and A. Bemporad, (2010) Model predictive control tuning by controller matching, IEEE Trans. Automat. Contr., vol. 55, no. 1, pp. 185–190, 2010.

[4] A. Beccuti, M. Lazar, W. Heemels, G. Papafotiou, and M. Morari, (2007) Assessment of Nonlinear Predictive Control Techniques for Dc-Dc Converters, IFAC Nonlinear Control Design Symposium, pp. 395-401, 22-24 August 2007, Pretoria, South Africa

[5] J. Weigold and M. Braun, (2006) Robust Predictive Dead-Beat Controller for Buck Converters, EPE-PEMC 2006: 12th International Power Electronics and Motion Control Conference, Proceedings, pp. 951–956, 30 August-1 September 2006, Portoroz, Slovenia

[6] S. Mariethoz, M. Hercegy, and M. Kvasnica,(2008) Model Predictive Control of Buck DC-DC Converter with Nonlinear Inductor, 11th IEEE Work. Control Model. Power Electron. COMPEL 2008, pp. 1–8, 17-20 August 2008, Zurih, Switzerland.

[7] V. S. P. Cheung, H. S. H. Chung, and H. Wang, “Predictive Control of Buck Converter Using Nonlinear Output Capacitor Current Programming,” Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, pp. 491–498, 21-25 Feb. 2010, CA, USA

[8] C. S. babu and M. Veerachary, (2005) Predictive Controller for Fourth Order Buck Topologies, INTELEC 05 - Twenty-Seventh International Telecommunications Conference, pp. 411-414., 18-22 Sept. 2005, Berlin, Germany

[9] Liuping Wand, (2009) Model Predicitive Control System Design And Implementation Using MATLAB, Springer London.