Modified Ziegler–Nichols Method for Tuning a PID Controller of Buck-Boost converter

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Introduction

Converter is electric circuit used to control transfer of electric power between electric source and consumer [19]. Increasing of number and complexity of electric devices caused evolvement of wide range of different converters. Level of possible currents varies between few mA and several hundreds of A. Converters differ by working principle, construction, energetic efficiency, dimensions, accuracy of regulation, transient state response and price. Very often, converters have to perform additional function of protecting load and system in the case of a component failure [6].

DC-DC converters are designed for converting direct current voltage from one to another level wherein output voltage has to be regulated with regard to disturbances [8]. It is expected, to provide stable output voltage for the wide range of resistances and input voltages. Varying of the resistance is caused by different consumers in electric circuit and varying of input voltage, usually, consequence of discharging, when batteries are used as source or electric current [16]. Because of positive properties, DC-DC converter becomes irreplaceable part of alternative and renewable energy power plants, portable devices and industrial installations. Some of illustrative examples of DC-DC converter applications are computer systems, communication equipment, microelectromechanical systems (MEMS), welding devices, DC motors [8,12]. In solar power plants, the converter provides direct connection of photovoltaic cells to the public network, without using batteries [9].

Thanks to the development of energetic electronic, construction of DC-DC converter can be done without transformer. This affected on reducing price and dimensions of the converter and increasing its efficiency. Due to high efficiency (up to 98%) and possibility of controlling output current electronically, switching-mode converters or switching-mode power supplies (SMPS) are dominant power converters in practice [1,7,16]. Since there are no significant losses, heat dissipation is reduced and consequently need for intensive cooling. Negative feature of switching mode converters is rippling of the output current but this problem can be easily overcome by using low-pass filter.

Pulse DC-DC converters operate on a principle of pulse-width modulation (PWM). A switch, used to control current flow from the input to output of electric circuit, is controlled by pulse generator. Within the time between two adjacent pulses, called switching period, the switch is open, at first, and then closed until the end of the period. Voltage regulation is achieved by adjusting appropriate on-to-off time ratio of pulse generator. Control is performed by control loop feedback mechanism (controller) which provides that output voltage asymptotically tends to the referent value in spite of disturbances [12]. New topologies of power converters are being constantly developed [3]. The basic groups are Boost (step-up) converter, which provides lifting of the output voltage and Buck (step-down) converter, which decreases the voltage. The third group is buck-boost converter which combines functionalities of both, above mentioned, switching-mode converters [1,10,16].

Designing of PID controller, for buck-boost converter, is complex because of the presence of nonlinearity. It is not possible to apply, directly, methods developed for projecting linear control systems. Because of that several strategies are developed for overcoming nonlinearity and each has its field of application [3-16]. This paper considers possibility of designing PID (proportional-integral-derivate) control, for buck-boost converter, as most accessible and in practice most usable form of automatic control. Modeling is done for the case of continuous conduction mode, where the output current is always positive. Parasitic resistances in the elements of the circuit are taken into account. By using mathematical model control law is designed. Simulation of control system is done by Matlab Simulink program packet and, on the basis of simulation results, brought out conclusions.

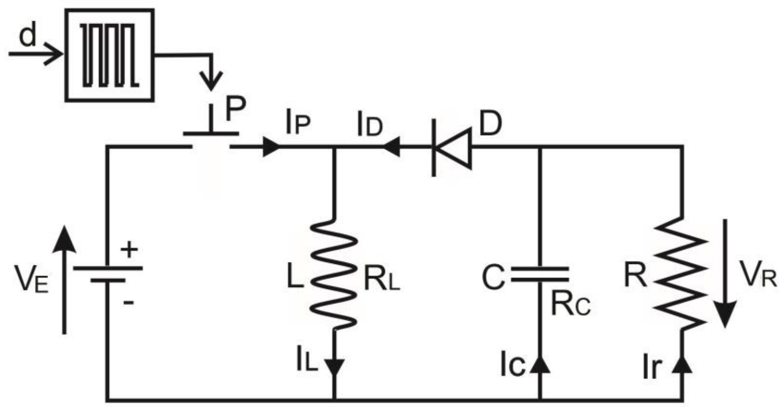

Figure 1 Electric circuit of buck-boost converter

Mathematical model

Working principle of buck-boost converter, as other switching mode converters, is based on opposition of inductor to the fast changing of electric current. Electric circuit of buck –boost converter is presented in Figure 1. The circuit elements are source of DC electric power V_E, power switch S, pulse generator, electromagnetic coil (inductor) L, diode D, capacity C and consumer of electric energy (passive resistance) R, with output voltage V_R. Beside basic elements, parasitic resistances in inductor, capacitor, switch and diode, respectively marked as R_L, R_C, R_P and R_D, are taken into consideration. The switch, used to separate electric source from other parts of the circuit, is controlled by pulse generator. Inverse of switching frequency is equal to switching period T of pulse generator. During one period the switch is open, at first, and then is closed so that electric circuit of buck-boost converter operates constantly rotating between two regimes

1. **The switch is closed** during the time interval dT, where $d \in (0,1)$ is ratio between time interval when switch is on and the whole switching period T called duty cycle. As diode D blocks current flow toward right part of circuit, it can only pass trough inductor L. The inductor gives resistance to fast changing of electric current causing slow change of

current while magnetic energy is accumulated. At the same time, in the right part of converter, electric capacity is discharging trough resistance R. In this regime, left and right parts of buck-boost converter are separated and operate as two independent electric circuits. Mathematical model of the converter, for the regime of opened switch, is presented by following differential equations

$$\left.\begin{aligned} C\frac{dV_C}{dt} &= -\frac{V_C}{R+R_C} \\ L\frac{dI_L}{dt} &= V_E - (R_L + R_s)I_L \end{aligned}\right\}, 0 < t < dT \tag{1}$$

where V_C is capacity voltage, I_L is inductor current, V_E input voltage and R output resistance. Using capacitor voltage and input current as space state variables, $x = [V_c \quad I_L]$, on the basis of the equation (1), state space model of buck-boost converter, for the regime of closed switch, is

$$\begin{aligned} \dot{x}(t) &= A_z x(t) + B_z V_E(t) \\ V_R(t) &= C_z\, x(t) \end{aligned} \tag{2}$$

where

$$A_z = \begin{bmatrix} -\dfrac{1}{C(R+R_c)} & 0 \\ 0 & -\dfrac{R_L+R_s}{L} \end{bmatrix} \quad B_z = \begin{bmatrix} 0 \\ \dfrac{1}{L} \end{bmatrix} \quad C_z = \begin{bmatrix} \dfrac{R}{R+R_c} & 0 \end{bmatrix} \tag{3}$$

2. **The switch is opened** since the moment dT until T, during the time interval $(1-d)T$. The magnetic energy, accumulated in inductor L, is releasing, in the form of electric current. It passes, further, trough capacity C, resistance R and diode D. Electric circuit behavior, in the regime of opened switch, is described by following differential equations

$$\left.\begin{aligned} C\frac{dV_C}{dt} &= -\frac{V_C}{(R+R_c)} + \frac{R}{(R+R_c)}I_L \\ L\frac{dI_L}{dt} &= -\frac{R}{(R+R_c)}V_C + (R_c||R - R_L - R_D)I_L \end{aligned}\right\}, dT < t < T \tag{4}$$

and on the basis of equatons (4), state space model of buck-boost converter, for the regime of opened switch, is

$$\begin{aligned} \dot{x}(t) &= A_o x(t) + B_o V_E(t) \\ V_R(t) &= C_o\, x(t) \end{aligned}$$

where

$$A_o = \begin{bmatrix} -\dfrac{1}{C(R+R_c)} & \dfrac{R}{C(R+R_c)} \\ -\dfrac{R}{L(R+R_c)} & \dfrac{R_c||R - R_L - R_D}{L} \end{bmatrix} \quad B_o = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad C = \begin{bmatrix} \dfrac{R}{R+R_c} & R_c||R \end{bmatrix} \tag{6}$$

One of the strategies for overcoming nonlinearity, of the switch, can be state-space averaging approach [14]. This method provides possibility of combining state-space models of two different working regimes (3,6) by employing duty cycle d. The result is unique mathematical model, called averaged or equivalent state space model [7], of buck-boost converter

$$\begin{aligned} \dot{x}(t) &= Ax(t) + BV_E(t) \\ V_R(t) &= C\,x(t) \end{aligned} \tag{7}$$

where

$$\begin{aligned} A &= \begin{bmatrix} -\dfrac{1}{C(R+R_c)} & \dfrac{R(1-d)}{C(R+R_C)} \\ -\dfrac{R(1-d)}{L(R+R_c)} & \dfrac{(1-d)(R_c||R - R_D) - R_L - dR_s}{L} \end{bmatrix} \\ B &= \begin{bmatrix} 0 \\ \dfrac{d}{L} \end{bmatrix} \quad C = \begin{bmatrix} \dfrac{R}{R+R_c} & (1-d)R_c||R \end{bmatrix} \end{aligned} \tag{8}$$

After Laplace transform of previous model (8), transfer function of equivalent system is

$$G(s) = \frac{V_R(s)}{V_E(s)} = \frac{d(1-d)}{LC(1+\alpha_C)} \frac{C\alpha_C \cdot s + 1}{s^2 + \dfrac{1}{1+\alpha_C}\left(\dfrac{1}{RC} - \dfrac{R\beta}{L}\right) \cdot s + \dfrac{1}{LC(1+\alpha_C)^2}((1-d)^2 - \beta)} \tag{9}$$

where the constants are

$$\begin{aligned} \alpha_L = \frac{R_L}{R}, \qquad \alpha_C = \frac{R_C}{R}, \qquad \alpha_D = \frac{R_D}{R}, \qquad \alpha_S = \frac{R_S}{R} \\ \beta = (1-d)(\alpha_C - \alpha_D) - (\alpha_L + d\alpha_s)(1+\alpha_C) \end{aligned} \tag{10}$$

If steady state is considering, state-space error is equal to zero ($\dot{x}(t) = [0 \quad 0]^T$) and transfer function of equivalent system equal to the gain of buck-boost boost converter is

$$M = \frac{d}{1-d} \frac{1+\alpha_C}{1 - \dfrac{\beta}{(1-d)^2}} \tag{11}$$

The first factor of the steady-state transfer function (11) is gain of the ideal buck-boost converter, wherein all parasitic resistances are neglected. Second factor takes into account losses of electric energy during it passes through real electric elements. Value of duty cycle, related to maximal gain of the converter, can be evaluated by equalizing first derivate of steady-state transfer function with respect to duty cycle with zero

$$\frac{\partial M}{\partial d} = \frac{(1-\alpha_C)d^2 - 2\beta d + \beta}{(d^2 + (\alpha_C - 2)d + \alpha_L(1+\alpha_C) + 1 - \alpha_C)^2} = 0 \tag{12}$$

which gives duty cycle

$$d = \frac{1 - \alpha_C + \alpha_L(1+\alpha_C) - \sqrt{\alpha_L(1+\alpha_C)(1-\alpha_C+\alpha_L(1+\alpha_C))}}{1-\alpha_C} \tag{13}$$

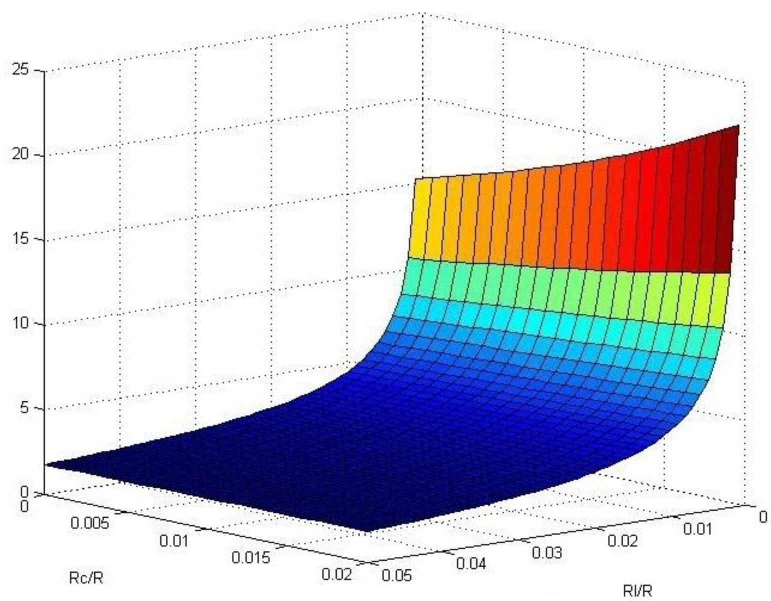

Figure 2 Maximal gain of buck-boost converter with respect to ratios Rl/R and Rc/R

Figure 2 illustrate dependence of maximal gain of buck-boost converter with respect to ratios α_l and α_c, respectively, ratio of inductor parasitic resistance and output resistance and ratio of parasitic capacity resistance and output resistance. It is obvious that maximal gain of the converter depends strongly on the ratio α_l. As this ratio trend to zero, buck-boost converter tends to ideal. So, it is desirable this ratio to be as small as it possible. On the other hand, as α_c rises maximal gain is growing. However, it is effect of big oscillations of output voltage which guides system to unstable state (Figure 13). That is why ratio α_c has to be as small as it possible too.

Condition of continual regime, which means that output current is always positive, is used for evaluation of necessary value of minimal inductivity. For the practical use parasitic resistance in branch of capacity can be neglected.

$$L > \frac{R(1-d)^2 + R_l(1-d)}{2f} \tag{14}$$

where f if swintching frequency. In the similar way, appropriate capacitance can be evaluated. It must be taking care that parasitic resistance not interferes with output voltage oscilation.

$$C = \frac{dTV_R}{2R\Delta V_R} \tag{15}$$

where ΔV_R is output voltage ripple [7].

Control design

Figure 3 is schematic representation of buck-boost converter electric circuit controlled by closed-loop PID control. Since output voltage V_R has opposite direction, in regards to the input voltage V_E and referent voltage V_{ref}, positive feedback is used for computation of tracing error E. Other solution would be negative feedback with negative unit gain at the output of the converter. Error signal enters the PID controller, which provides that output value follows the referent one. Controller output is attached to saturation element and output of saturation to pulse generator. The saturation element is used to limit signal of error by the upper and lower saturation values because the input signal of pulse generator is expected to be inside this range. For the case of ideal switch the lower saturation level is zero and the upper is one. If one takes into account time interval necessary for opening and closing of the switch, these limits would be moved toward reducing the range. The range of saturation is scope of active control because control signal out of this range have no effect on system behavior. To perform control of the system, all the time, it is necessary that control signal stays within the range of saturation.

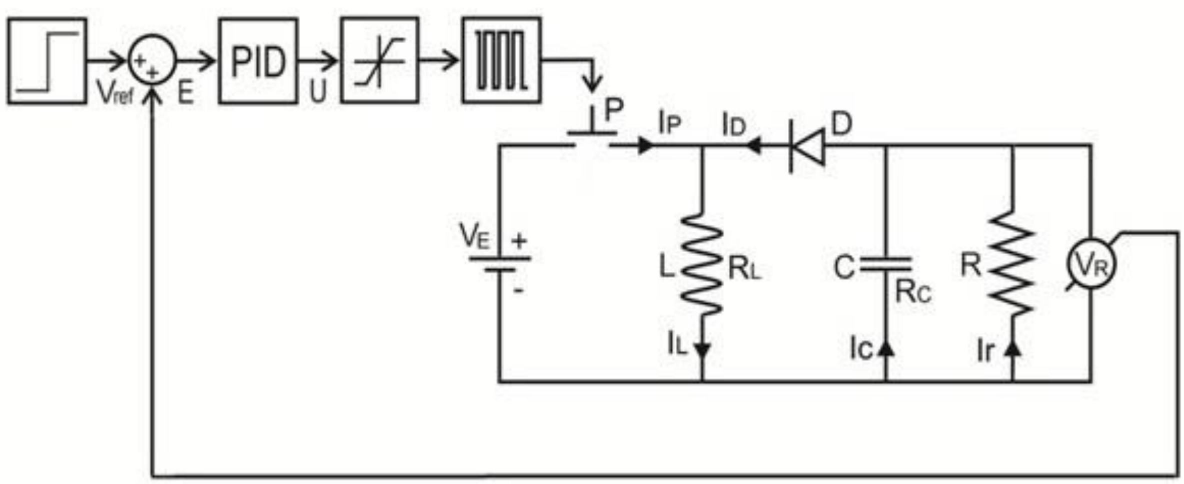

Figure 3 PID control of buck-boost converter

Maximal gain of ideal buck-boost converter is unlimited. Real converter, however, has limited maximal gain because of losses of parasitic resistances in real elements of the circuit. Maximal gain is physical property of the electric circuit and can't be overcome by applying specific control law. The gain can be evaluated by using equation (11) or its graphical representation in the Figure 4. The graph represents dependency of maximal gain with respect to duty cycle d, for the case of ideal and case of the real buck-boost converter. When designing PID control law for buck-boost converter, maximal value of the referent signal should be above limited so that gain never exceeds maximal possible level.

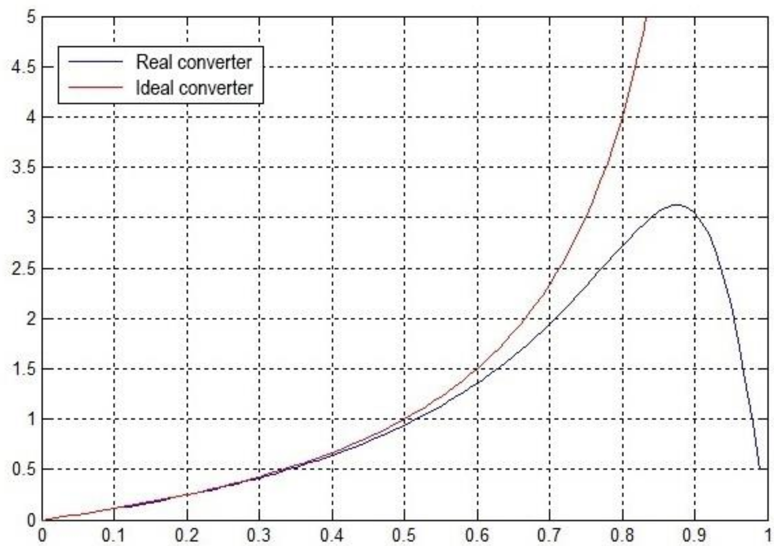

Figure 4 Maximal gain of buck-boost converter

One of the basic tasks, controller usually has to do, is to provide system stability within steady state. The root locus of the equivalent system transfer function is shown in the Figure 5. It is obvious, according to the graph, that closed loop system is stable for any value of proportional gain. It means closed loop control system is stable by itself. The second request is that output voltage asymptotically tracks referent value and PID controller has to generate control law in order to fulfill it.

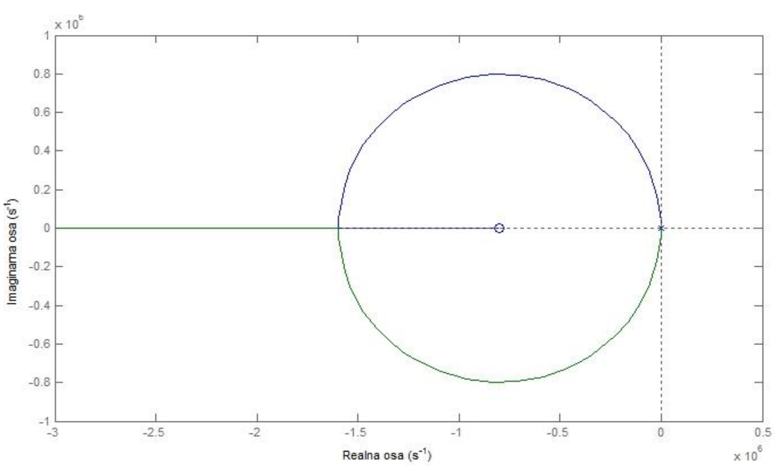

Figure 5 Root locus of the transfer function of equivalent circuit of buck-boost converter

Basic form of PID control law is given by following equation

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \tag{16}$$

which gives transfer function of PID controller of the shape

$$C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s = K_p \left(1 + \frac{1}{sT_i} + sT_d\right) \tag{17}$$

where K_p, K_i and K_d are, proportional, integral and derivate gain, respectively, and constants $T_i = K_p/K_i$ i $T_d = K_d/K_p$[17].

PID controller indirectly, by pulse generator, controls duration of the switch on-state within one switching period. Level of control signal is limited, theoretically, by zero and one. This is symbolically represented as saturation on the block diagram of buck-boost converter in Figure 3. The limitation introduces new nonlinearity, which is not taken into consideration during evaluation of state space model (8) and transfer function (9). If level of control signal overcomes saturation scope, it keeps border value and system becomes insensitive to further changes of error signal. One should be very careful when tuning PID controller and try to avoid scope of nonlinearity.

Assuming that control signal is within range of saturation, using expression (11) or graph in Figure 4, can be evaluated level of duty cycle d which provides desired gain of buck-boost converter

$$d = \frac{1 + M(2-\beta_p) - \sqrt{\left(1 + M(2-\beta_p)\right)^2 - 4M(1+M+\alpha_C)(1-\beta_L)}}{2(1+M+\alpha_C)} \tag{18}$$

where constants are

$$\beta_p = \alpha_C - \alpha_D - \alpha_P(1+\alpha_C) \qquad \beta_L = \alpha_C - \alpha_D + \alpha_L(1+\alpha_C) \tag{19}$$

In previous expressions, values α_C, α_P and α_D have theoretical meaning. These values are so small, don't have significant influence to the value of duty cycle, and that is why can be neglected for the purpose of PID controller tuning. The goal designing control law, for buck-boost converter, is that control signal, due to step raise of referent value, rise uniformly from zero to the final value of duty cycle d. In such way, it is secured that control signal never lefts the zone of active control. Output valu is also expected to raise uniformely from zero to referent value.

In the moment of step bounce of referent signal output voltage is still zero and error signal E is equal to referent voltage. In order to prevent control signal from overcoming upper limit of the saturation, maximal allowed proportional gain should be equal to the inverse of referent signal

$$K_{p\,max} = \frac{1}{V_{ref}} \tag{20}$$

Any higher gain would result in control signal higher than upper limit of saturation and control would be disturbed. Critical value of proportional gain K_{cr}, applicable for PID designing, is obtained by multiplying maximal allowed gain (20) by duty cycle d which, according to the expression (11), corresponds with the desired gain of converter.

$$K_{cr} = dK_{p\,max} = \frac{d}{V_{ref}} \tag{21}$$

Thus, influence of converter gain M to the control law is formally introduced and provided uniform step response within whole scope of possible gains of the converter. Critical period of oscillations T_{cr} is obtained by measuring period of oscillations related to the maximal allowed proportional gain $K_{p\,max}$. In the case of buck-boost converter it is the minimal oscillatory period can be measured at all and corresponds to undamped oscillations of the output. It will be assumed that this period approximate system critical period with adequate accuracy for the purpose of PID tuning.

Alternative approach can be to evaluate critical oscillatory period on the basis of equivalent system transfer function. It will be adopted the shortest possible period of oscillations which occurs in the converter circuit. Referring to expression (9), the minimal possible oscillatory period of the equivalent system corresponds with the zero value of duty cycle. After neglecting all of parasitic resistances, the critical oscillatory period of the equivalent system is given by expression

$$T_{cr} = 2\pi\sqrt{LC} \tag{22}$$

Controller	K_p	T_i	T_d
P	$0{,}5K_{cr}$	∞	0
PI	$0{,}45K_{cr}$	$1{,}2K_p/\ T_{cr}$	0
PID	$0{,}6K_{cr}$	$2K_p/\ T_{cr}$	$K_pT_{cr}/8$
PID small overshoot	$0{,}33K_{cr}$	$2K_p/T_{cr}$	$K_pT_{cr}/3$
PID without overshoot	$0{,}2K_{cr}$	$2K_p/T_{cr}$	$K_pT_{cr}/3$

Table 1 Ziegler-Nichols parameters of PID controller

Using adopted values for K_{cr} i T_{cr} and Ziegle-Nichols recommendations [17] for PID tuning without overshoot (Table 1), unknown parameters of PID controller could be evaluated as

$$K_p = 0{,}2\frac{d}{V_{ref}} \qquad K_i = \frac{2K_p}{T_{cr}} \qquad K_i = \frac{K_pT_{cr}}{3} \tag{23}$$

Simulation

Results of theoretical analysis are examined by simulation of PID controlling of buck-boost converter using Matlab Simulink. Simulation is done by Simulink model shown in Figure 6 and parameter of electric circuit are given in Table 2. The frequency of pulse generator, used in all simulations, is $10^{-5}\ s$.

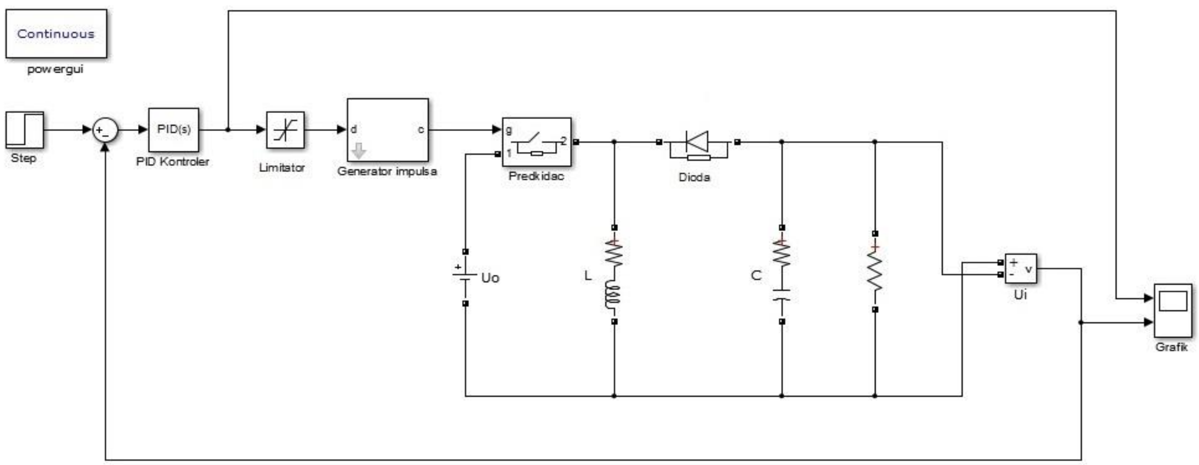

Figure 6 Simulink model of buck-boost converter with PID control

Element	Physical property	Value
Inductor	Inductivity	$L = 270 \times 10^{-6}\ H$
	Resistance	$R_l = 0.5\ \Omega$
Capacity	Capacity	$C = 50 \times 10^{-6}\ F$
	Resistance	$R_c = 0.15\ \Omega$
Resistance	Resistance	$R = 20\ \Omega$
Diode	Resistance	$R_D = 0.001\ \Omega$
Power switch	Resistance	$R_P = 0.001\ \Omega$

Table 2 Circuit parameters of buck-boost converter

The first simulation is performed for the input voltage $V_E = 24\ V$ and referent voltage $V_{ref} = 48\ V$ with proportional gain $K_p = 0{,}021$. This gain is slightly higher than maximal allowed, which is $K_{p\ max} = \frac{1}{V_{ref}} = 0.0208\ s$. Control signal and output voltage step response is shown in the figure 7. Step rise of referent signal results in step bounce of the error. Since proportional gain K_p is higher than critical, control signal exceeds upper limit of saturation and system stops to respond to further motion of the error signal. After gentle step, toward negative direction, which is consequence of system inert ion, output value tends to zero asymptotically and constrol signal stays trapped at the level higher then upper limit of saturation.

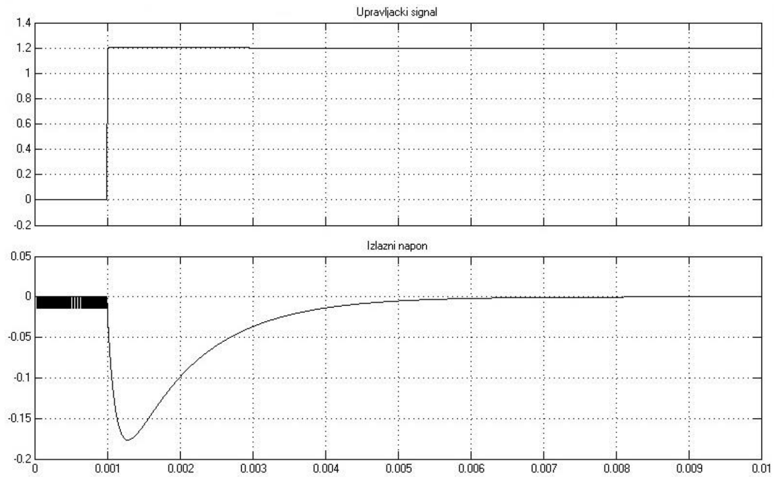

Figure 7 Step response of buck-boost converter with overcritical proportional gain

In the second simulation all parameters stay the same except proportional gain which is $K_p = 0{,}0205\ s$. It is slightly lower then maximal allowed gain (20) which provides active control of the converter. Figure 8 shows that control signal, after step response of the referent voltage, reaches value slightly lower than upper limit of saturation. By oscillating, around steady state value, in one moment control signal drops under lower limit of saturation but after that it returns back in the scope of active control. Output voltage tends to steady state value which differs from referent value by significant amount.

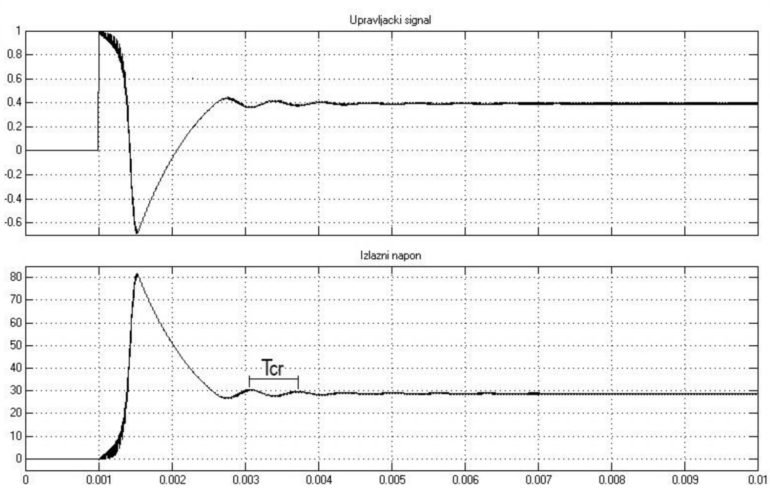

Figure 8 Step response of buck-boost converter with under critical proportional gain

The resulting graph (Figure 8) will be used for assessment of critical period T_{cr}. It will be measured as time interval between second and third positive pick of the output response. It is the first oscillatory period which completely happens in the regime of active control. In the case of current simulation this period is $T_{cr} \approx 9 \times 10^{-4}\ s$. The period is higher then actual critical period but difference can be neglected from the PID tuning point of view. The second approach (22) of obtaining critical oscillatory period gives $T_{cr} \approx 7.3 \times 10^{-4}\ s$.

One more parameter, necessary for applying PID tuning equations (21), is duty cycle d. For the proposed volgtages, gain of the converter is $M = \frac{V_{ref}}{V_0} = 2$ and related duty cycle is, according to equation (18), $d = 0.7271$. After all, necessary, parameters are adopted necessary gains of the PID controller are $K_p \approx 3 \times 10^{-3}$, $K_i \approx 8{,}3$ i $K_d \approx 7 \times 10^{-7}$.

After applying evaluated gains to PID controller, control signal and closed loop step response of the buck-boost converter looks like in the Figure 9. It is obvious that the aim is fulfilled. The control signal never lefts scope of the saturation element. After initial bounce, limited by adopted gain, it uniformly raises until reaches level of the duty cycle d. The output voltage grows, also without oscillations, before it comes to referent value. The raising time is approximately 8 ms.

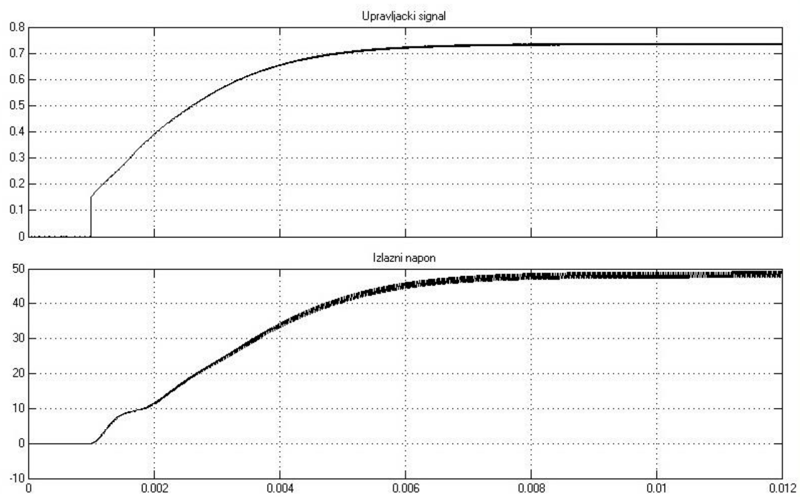

Figure 9 Step response of buck-boost converter with PID control

Next few simulations investigate robustness of designed PID control of buck-boost converter to uncertainty of system parameters. The first subject of observation is input voltage V_E. According to the steady state transfer function (11), illustrated in Figure 4, it can be infinitely reduced. Thus for the constant output voltage input voltage has no upper limit. Referring to the same law, lower limit of input voltage is determined by maximal gain of the converter. Replacing parameters in the equation (13) gives maximal gain of $M = 2{,}77$. For the referent voltega of $V_{ref} = 48\ V$ minimal input voltage is $V_E = 17{,}32\ V$. Simulation confirms slightly higher value of input voltage, due system stays stable (about $18{,}3\ V$) which relate to the maximal gain of $M = 2{,}62$. Figure 10a show step response of the output voltage for the input voltage $V_E = 17{,}32\ V$. The shape of the response and settling time stay almost unchanged. The result of simulation in Figure 10b, obtained for the input voltage of $V_E = 96\ V$ and the same output voltage, shows oscillations

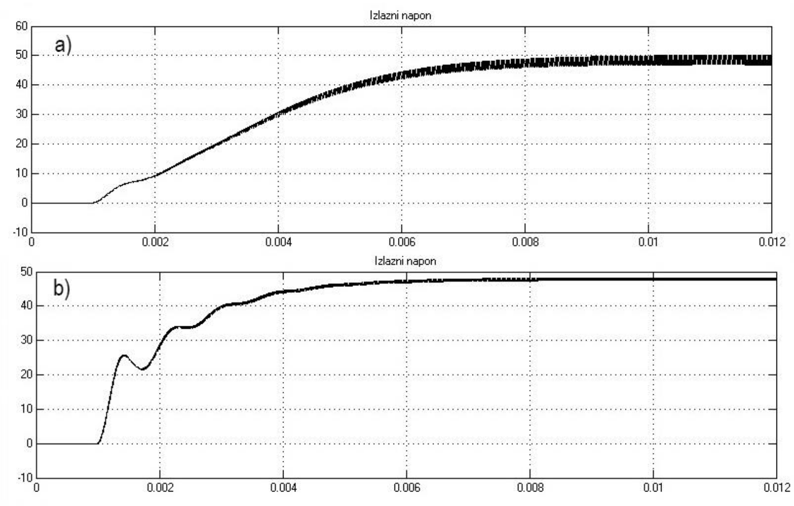

Figure 10 Step response of the buck-boost converter with PID control: a)$V_E = 18{,}3\ V$, b)$V_E = 96\ V$

in step response of output voltage while the settling time is slightly reduced. Input voltage, in the practice, doesn't reach such level of uncertainty, especially in positive direction. Thus, current PID configuration should be considered as stable for the positive disturbances of input voltage and below limited by maximal gain.

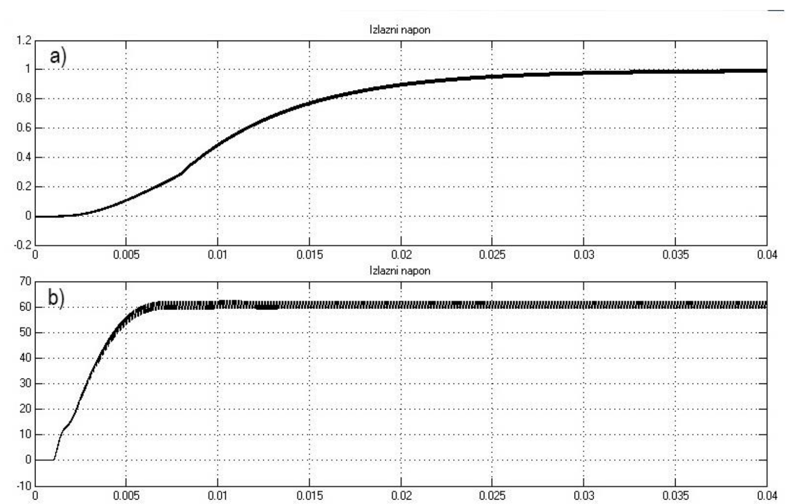

Figure 11 Step response of the buck-boost converter with PID control: a)$V_{ref} = 1\ V$, b)$V_{ref} = 60\ V$

Using the same law (11), for the case of output voltage, results in reverse conclusion. There is no lower limit of the referent voltage because input voltage can be infinitely reduced by buck-boost converter. Simulation result of step response, obtained using input voltage of $V_E = 24\ V$ and referent voltage of $V_{ref} = 1\ V$ is shown in figure 11a. It is obvious negative effect of referent voltage reduction to the settling time. In the current simulation it is about 40 ms which is 5 times longer then settling time in the case of nominal referent voltage. The upper limit of referent voltage is caused by maximal gain of the buck-boost converter. Figure 11b shows step response of output voltage V_R, due same parameters of the controller, and for the referent voltage of $V_{ref} = 60\ V$, slightly lower than maximal possible. It can be noticed amplification of oscillations but decreasing of settling time. The control system stays completely operational.

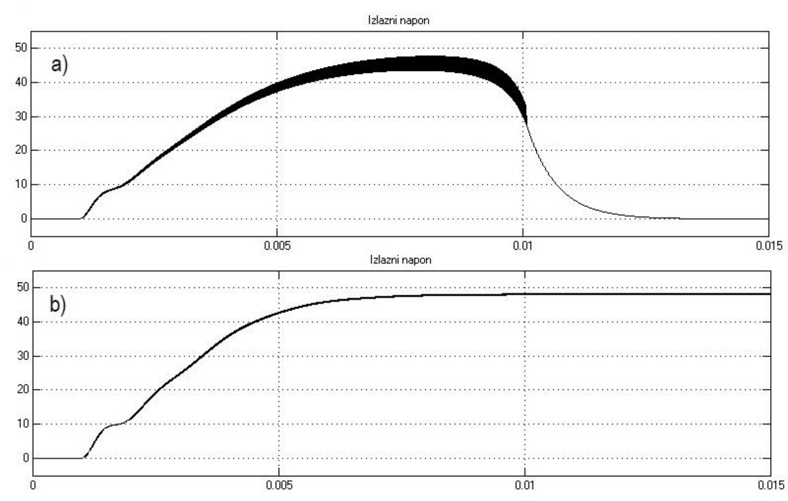

Figure 12 Step response of the buck-boost converter with PID control:a)$R = 12\ \Omega$, b)$R = 100\ \Omega$

To examine influence of output resistance uncertenity to the control system behavior simulation (Figure 12) is done with the constant voltage of $V_E = 24\ V$ and referent value of $V_{ref} = 48\ V$. Compared to the two previous cases, very similar conclusions are obtaind. Lower limit of outpur resistance, due system stays stable, is about $12{,}7\ \Omega$. The reason is obvious (11), as the output resistance decreases maximal gain also decreases. For the minimal voltage of $12{,}7\ \Omega$ maximal gain is about $M = 2$, equal to scheduled value. For the resistance below minimal, maximal voltage of $48\ V$ goes out the range of possible referent values and output voltage fails in following referent value. System robustness for the positive change of output resistance is much higher. Step responce of the control system for the output reistance 5 times higher than nominal ($R = 100\ \Omega$) is shown in the Figure 12b.

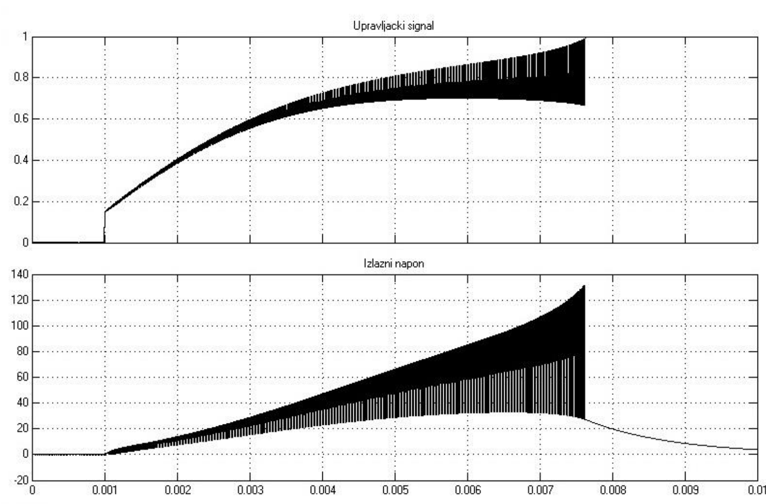

Figure 13 Step response of the buck-boost converter with high parasitic resistance in the branch of capacity ($R_C = 4\ \Omega$)

It is obvious and well described in literature influence of parasitic resistance to the maximal gain of buck-boost converter. On this occasion, influence of parasitic ressistance to the maximal gain is explored. In Figure 13 it is shown step response of the buck-boost converter with the big resistnace in the brunch of capacity ($R = 4\ \Omega$). Rippling of the output voltage can be seen which consequently drives system avay of referent value (Figure 12).

Conclusion

This paper expores designing principles and efficiency of PID controling of buck-boost converter. Using averaging principle eqvivalent mathematical model of the converter is obtained. It provides usefull system parameters, with the appropriate accuracy for the purpose of PID tunning. Based on this parameters and Ziegler-Nicols rules for PID tuning, a simple tuning method is proposed for the buck-boost converter control design. Theoretical assumptions are confirmed by simulation in Matlab Simulink and high efficiency of proposed method too. The control system robustness due uncertenity of system parameters is also explored. The result of simulation establishes maximal gain of buck-boost converter as basic factor of limitation. The gain is physical property of the converter and can't be improved by control law. Despite of high roubustness, it is noticeable decreasing of step response performance with the changing of system parameters. Because of this, future work could be oriented to deploying of adaptive control, based on proposed method, which could provide real time adjusting of the PID controller.

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