

COMPUTER AIDED DESIGN OF SIMULATION AND EXPERIMENTAL MODEL OF BUCK-BOOST CONVERTER

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Abstract: Paper summarizes the conducted research in developing buck-boost converter for faculty laboratory. Firstly, mathematical model of converter is developed by computing all necessary elements and their proper sizing is done with respect to the output voltage ripple. After sizing the electronic components computer simulation model in software program PowerSim is developed enabling evaluation of converter operation at different duty cycles. Values of output voltage at different duty cycles from mathematical model are verified with simulation results. Final step in developing the converter is building the experimental model, based on detailed design of electronic circuit in software DesignSpark which enables complete design of printed electronic board for mounting the electronic components. Output voltages from experiment are measured and compared with mathematical and simulation results and experimental model is verified to be accurate enough for laboratory purposes.

Key words: buck-boost converter, simulation model, experimental model.

1. INTRODUCTION

Buck-Boost converter is well known DC-DC converter having wide application in many industrial processes. Designing of Buck-Boost converter is always a challenging task with respect to proper design of electronic components: capacitor and inductor and obtaining the prescribed values of ripple factor of output voltage and current. Software packages are always useful simulation tools which allow prediction of circuit behavior and its components. In this paper simulation software PowerSim is used for modeling the Buck-Boost converter which allows obtaining different output DC voltage with respect to different duty cycles of main switch usually MOSFET transistor from one constant value of input DC voltage. The general circuit of Buck-Boost converter is presented in Fig. 1 [1]. MOSFET transistor operates at 100 kHz and the ratio of time when main switch S in on- T_{on} and the total operation time- $T_p=T_{on}+T_{off}$ is known as duty cycle K. Input and output voltages are related to each other with relationship [2]:

$$K = \frac{V_o}{V_o - V_{in}} \quad (1)$$

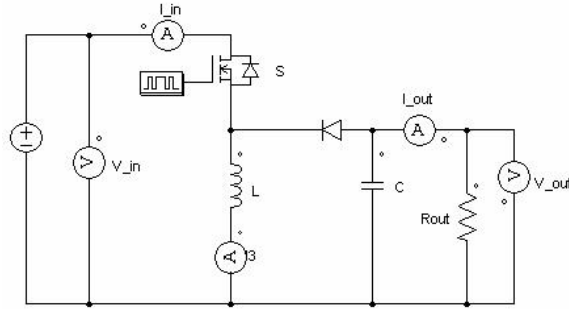


Fig.1. General circuit of Buck-Boost converter in PowerSim program

In dependence of the value of duty cycle in case when $K < 1/2$ output voltage V_o is less than input voltage V_{in} , while for $K > 1/2$ V_o is greater than input voltage V_{in} . Mathematical model based on calculation of electronic components inductor and capacitor is built within prescribed limits of variation of input and output voltage. Simulation circuit is built in software PowerSim based on calculated components and expected values of output voltage in dependence of duty cycle [3]. Two different cases are evaluated: duty cycle less than 0.5 i.e. 0.3 and duty cycle larger than 0.5 i.e. 0.7. Practical design of buck-boost converter is performed in software program DesignSpark 5.1 which gives the layout of printed board. Practical measurements of developed converter are realized in faculty laboratory proving the developed converter to be accurate enough.

2. MATHEMATICAL MODEL

First step in building of buck-boost converter was proper problem definition. It chosen to be built buck-boost converter with input voltage $V_{in} = (10 \div 12)V$, output voltage $V_{out} = (5 \div 24)V$, switching frequency of main switch S is $f = 100$ kHz, output current $I_{out} = 2A$, and variations of input current and voltage should be in prescribed limits $I = 0.1A$ and $U = 0.3V$. Minimal duty cycle is calculated from:

$$K_{min} = \frac{U_{out\ min}}{U_{out\ min} + U_{in\ min}} = \frac{5}{5 + 12} = 0.3 \quad (2)$$

while maximum duty cycle is calculated from:

$$K_{max} = \frac{U_{out\ max}}{U_{out\ max} + U_{in\ min}} = \frac{24}{24 + 10} = 0.7 \quad (3)$$

Maximal and minimal values of inductor are calculated from:

$$L_{min} = \frac{K_{min} U_{in\ min}}{\Delta I_{in} \cdot f} = \frac{0.3 \cdot 10}{0.1 \cdot 100 \cdot 10^3} = 0.0003H = 300\text{-}H \quad (4)$$

$$L_{max} = \frac{K_{max} \cdot U_{in\ max}}{\Delta I_{in} \cdot f} = \frac{0.7 \cdot 12}{0.1 \cdot 100 \cdot 10^3} = 0.00084H = 840\text{-}H \quad (5)$$

and maximal and minimal values of the capacitor are calculated from:

$$C_{\min} = \frac{K_{\min} \cdot I_{out}}{f \cdot \Delta U} = \frac{0.3 \cdot 2}{100 \cdot 10^3 \cdot 0.3} = 20 \sim F \tag{6}$$

$$C_{\max} = \frac{K_{\max} \cdot I_{out}}{f \cdot \Delta U} = \frac{0.7 \cdot 2}{100 \cdot 10^3 \cdot 0.3} = 46 \sim F \tag{7}$$

In order to have lower ripple of the inductor current and output voltage, maximal values of the inductor and capacitor are taken into consideration in simulation and experimental model. Based on above calculated values simulation model is built (Fig. 1).

3. SIMULATION MODEL AND RESULTS

In simulation model control of transistor is done with PWM signal and the duty cycle of main switch is set to be (30÷70)%. Chosen frequency of PWM signal which controls the main switch-S is 100 kHz. Ripple of the output voltage is determined from the value of the output capacitor. In order ripple of the output voltage to be lower capacitor value of 46 µF is implemented in the circuit of buck-boost converter. Simulation is performed for two separate cases: K=0.3, U_{in}=12V and according to (1) U_{out} should be 5.1 V and K=0.7, U_{in}=10V and according to (1) U_{out} should be 23.3 V. Simulation results of output voltage for both cases K=0.3 and K=0.7 are presented on Figs. 2 and 3 respectively.

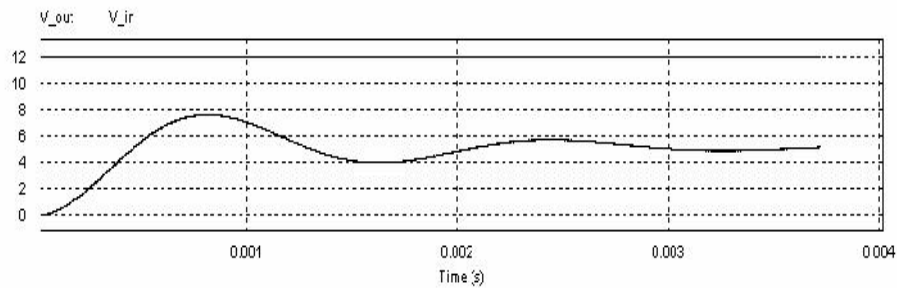


Fig.2. Input and output voltage at $K_{\min}=0.3$

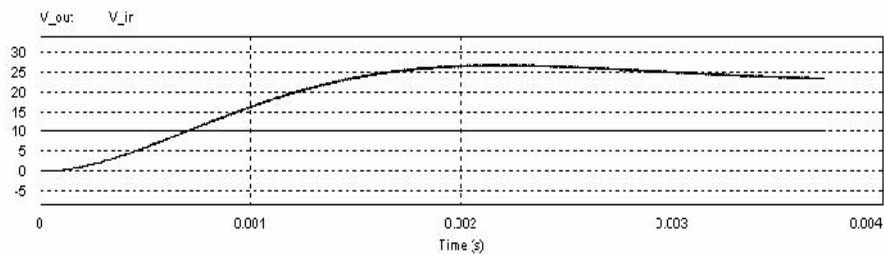


Fig.3. Input and output voltage at $K_{\max}=0.7$

According to the problem definition variation of output voltage should be in prescribed limits $\Delta U=0.3V$ and variation of input current should be $\Delta I=0.1A$. On Fig.4 is presented ripple of the output voltage from simulation model and it is found to be $\Delta U=0.25 V$ which confirms the starting assumption of ripple voltage $\Delta U=0.3V$. Starting design limitation was to have ripple of the output current of $\Delta I=100 mA$. Simulation model was realized with current ripple of $\Delta I=99.5 mA$ which proves the accuracy of simulation model.

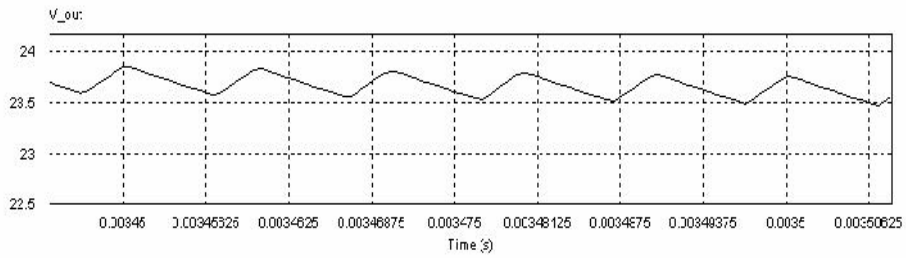


Fig. 4. Ripple of the output voltage from buck-boost simulation model

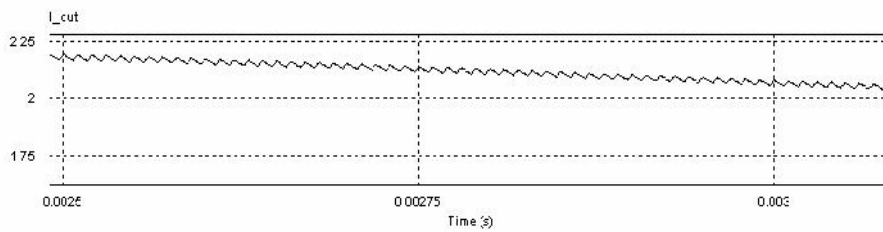


Fig.5. Ripple of input current in buck-boost simulation model

4. EXPERIMENTAL MODEL AND RESULTS

First step in practical realization of converter was development of printed circuit board which was designed in software package Design Spark 5.1 and it is presented in Fig. 6.

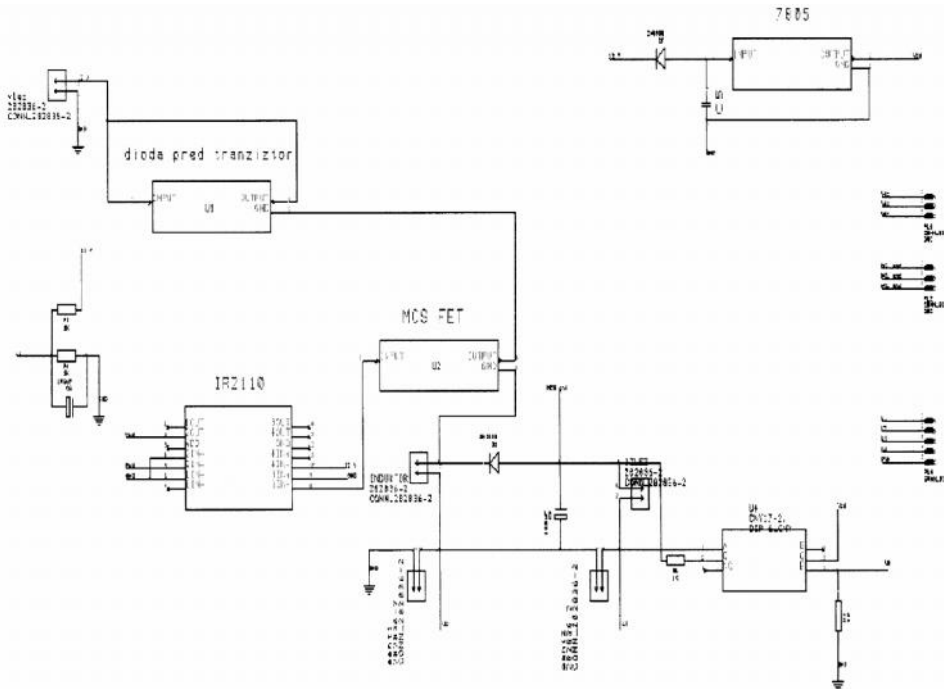


Fig. 6. Design of printed circuit board of buck-boost converter

Final design of printed circuit board (PCB) in 3D and its top view are presented in Fig.7.

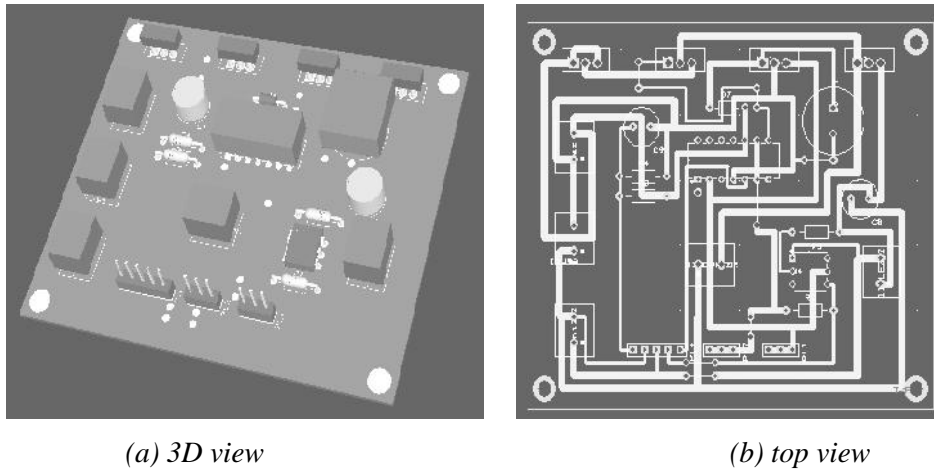


Fig.7. Printed circuit board layout

Practical realization of converter is based on electrical circuit presented in Fig.8.

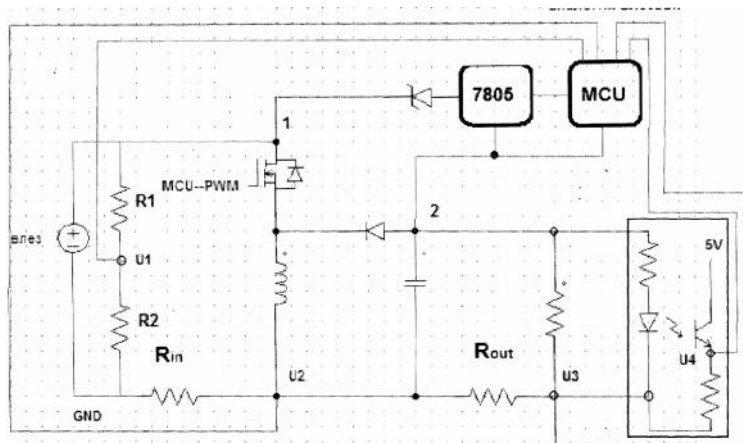


Fig.8. Electrical circuit of experimental buck-boost converter

PWM signal which controls the transistor duty cycle is obtained by microcontroller PIC16F876 which has available four measured signals with measuring range 0 to 5 V [4]. Voltage levels of 0 and 5 V are not the adequate ones for turning on and off the P-channel MOS transistor. In order PWM signal to be adjusted driver for control of MOSFET and IGBT transistor –IR2100 is used.

Transistor control circuit is presented in Fig. 9.

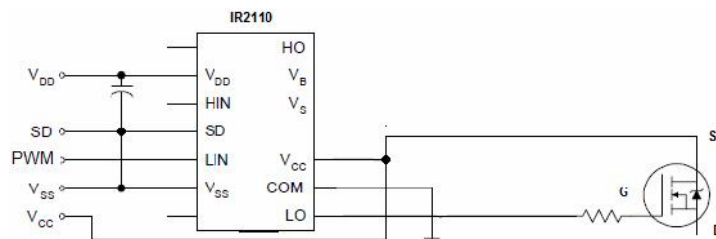


Fig. 9. Circuit for transistor control

Circuit IR2110 poses double driver but for the purpose of our experimental converter only one driver will be used. From Fig.9 it can be concluded that circuit input signals are SD enabling signals and LIN port on which PWM signal is input. In Fig. 10 is presented internal part of IR2110 or part of the driver aimed for control of the circuit.

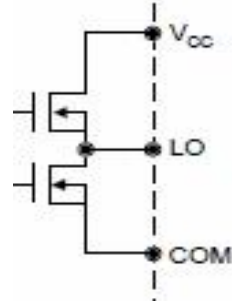


Fig. 10. Internal part of IR2110

Output voltage U_4 is measured by using optical couple LED diode and photo transistor. Output currents are measured from the voltages of input and output shunt U_2 and U_3 as well as from the resistance R_{out} (Fig.8):

$$I_{out} = \frac{U_2 - U_3}{R_{out}} \quad (8)$$

Based on developed computer design (Fig. 7), calculated electronic components and developed design of transistor control circuit, experimental model of buck-boost converter is developed and it is presented in Fig. 11.

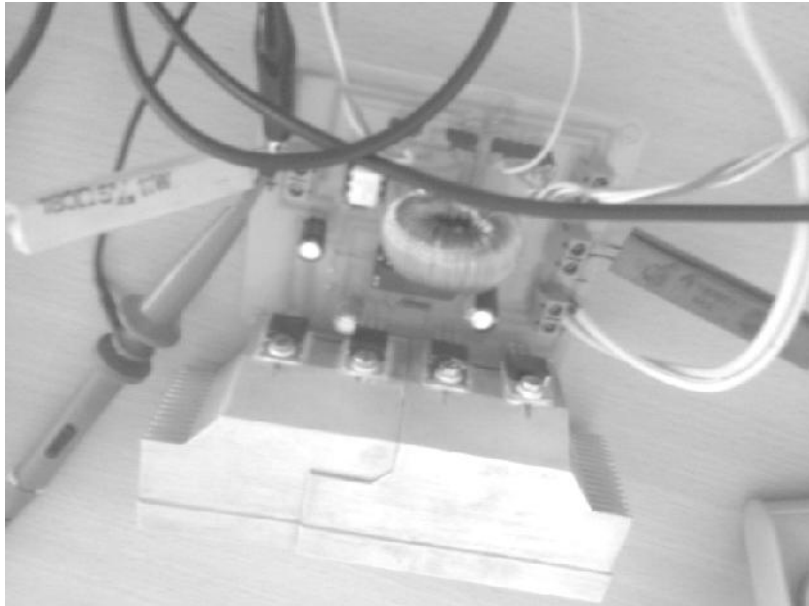


Fig. 11. Experimental model of buck-boost converter

Based on simulation results duty cycle is set to be $K=0.3$ in experimental circuit and the output voltage measured by the oscilloscope is 6V (Fig.12). In second case for duty cycle of $K=0.7$ in experimental model is measured voltage $V_{out}=21$ V (Fig.12).

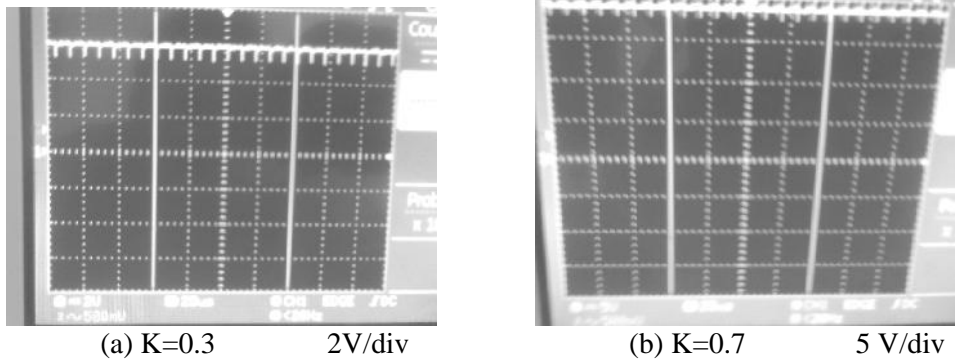


Fig. 12. Measured output voltage from experimental model

Comparison of results from mathematical, simulation and experimental results are presented in Table 1.

Table 1.

V_{out}	Mathematical model	Simulation model	Experimental model
$K=0.3$	5.14 V	5 V	6 V
$K=0.7$	23 V	23.7	21

Presented results in Table 1 show good agreement between mathematical and simulation model and some variation from prescribed values of output voltage in experimental model due to the value of output resistor R_4 . Also there are some variations of output voltage in experimental model which can be further smoothed with usage of adequate filter elements.

4. CONCLUSION

Buck-boost converter is well known DC/DC converter aimed for DC power supply of different electrical devices where DC voltage is required. It enables delivery of output DC voltage which can be smaller or greater than input voltage in dependence of duty cycle of the transistor. Different software packages developed for application in electrical engineering has made the engineering work easier and more accurate due to possibility of fast development of simulation models which give the accurate results almost instantly. In this paper developed simulation model of the converter based on previous mathematical calculation of the main components of the converter (inductance and capacitor) is simulated in simulation software PowerSim for two different duty cycles of the transistor $K=0.3$ and $K=0.7$. Simulation is based on assumption that variation of output voltage is $U=0.3V$ and variation of input current is $I=0.1A$. Obtained simulation results showed good agreement with prescribed limits of variation of output voltage and input current i.e. $\Delta U=0.25 V$ and $\Delta I=99.5 mA$ while in the same time output voltage for duty cycle $K=0.3$ is 5 V from simulation showing very good agreement with calculated output voltage of 5.14 V. Also in case of duty cycle of 0.7 calculated output voltage of 23 V is on good agreement with output voltage from simulation model of 23.7 V proving the simulation model to be accurate enough. Software package Design Spark 5.1 is used for designing the printed board of converter which is letter printed on circuit board. Microcontroller PIC 16F876 is used for generating PWM signal for controlling the duty cycle of transistor.

Obtained experimental results of output voltage shows reasonable agreement for both duty cycles of converter with calculated and simulation results. Some differences of output voltage from experimental model compared output voltage from calculations and simulations are noticeable mainly due to available output shunt for measuring the output voltage. Still for faculty laboratory purposes it can be considered experimental model to be accurate enough with possible further improvement with adequate shunt resistor. Future research should focus on development of adequate model for control of DC electrical machines with DC/DC converter, firstly with building the simulation model by computer aided design and afterwards its implementation in control of electrical machines.

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