Step-up Converter for Students Teaching

Mihai RAȚĂ[1], Cristian DRANCA[2], Gabriela RAȚĂ[1], Ciprian AFANASOV[1]
[1] - "Stefan cel Mare" University of Suceava
str.Universitatii nr.13, RO-720229 Suceava
[2] - Electroalfa Botoşani
mihair@eed.usv.ro, gabrielar@eed.usv.ro, aciprian@eed.usv.ro

***Abstract* — This paper presents a solution for the experimental study of the steady-state characteristics from the step-up (boost) converter circuits by the students. The main feature of the proposed solution consists in possibility to observe the influence of the inductor value L, the switching frequency f_s, the duty cycle α and the output current I_o to the converter.**

***Index Terms* — DC-DC power conversion, educational technology, frequency control, MOSFET switch, power electronics**

I. INTRODUCTION

DC-DC converters are widely used in regulated switch-mode dc power supplies and in dc motor drive applications. Switch-mode dc-dc converters (called SMPS – Switched Mode Power Supplies) are used to convert the unregulated dc input into a controlled dc output at a desired voltage level (Fig. 1).

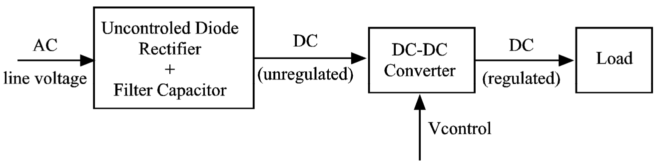


Fig. 1 DC-DC converter system

The main features of SMPC are high efficiency and high power density. There are uses in many domains like Computer, telecom, automotive and domestic application.

Most power supplies are design to meet some or all the following requirements:

- regulated output;
- isolation;
- multiple outputs.

The basic dc-dc converter topologies, without electrical isolation, are the step-down and step-up converter. [1]

In this paper we propose a solution to make more attractive for students the power electronics labwork. This solution wants to be more educative for students. One teacher have the success at his labwork when the students understand how work the study schema and what influence have some parts of schema in good work of the converter.

II. STEP-UP CONVERTER

As the name implies [1], a step-up converter produces a upper average output voltage than the dc input voltage V_i. This converter is realized to work for a pure resistive load, as show in Fig. 2.

One of the methods for controlling the output voltage employs switching at a constant frequency (hence, a constant switching time period $T_s = t_{ON} + t_{OFF}$), and adjusting on the on-duration of the switch to control the average output voltage. In this method, called Pulse-Width Modulation (PWM) switching the switch duty ratio α, which is defined as the ratio of the on-modulation to the switching time period ($\alpha = t_{ON}/T_s$), is varied.

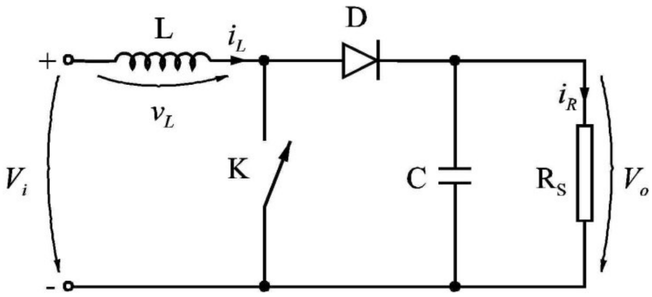


Fig. 2 Step-up converter

The average output voltage, for step-up converter, controlled by controlling the switch on and off durations (t_{ON} and t_{OFF}) is:

$$V_o = \frac{V_i}{1-\alpha} \qquad (1)$$

Fig.3 illustrates the steady-state waveforms for continuous conduction where the inductor current i_L flows continuously.

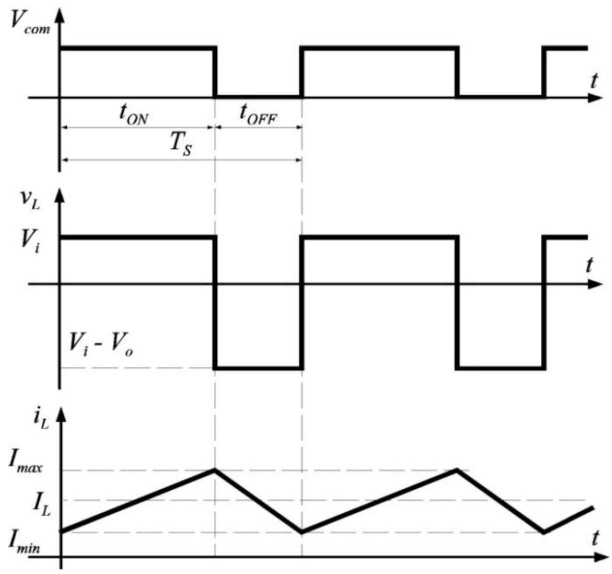


Fig. 3 Continuous conduction in step-up converter

At boundary between continuous and discontinuous conduction, the inductor current i_L goes to zero at the end of the off interval. The average value of inductor current at this boundary is:

$$(I_L)_B = \frac{[\alpha \cdot T_s + (1-\alpha)\cdot T_s]}{2T_s}\cdot (I_L)_{B\,peak} = \frac{(I_L)_{B\,peak}}{2} \qquad (2)$$

where, $(I_L)_{B\,peak}$ the maximum value of inductor current, in this condition of conduction, is:

$$(I_L)_{B\,peak} = \frac{U_o}{L}\cdot \alpha(1-\alpha)\cdot T_S \qquad (3)$$

Because $I_L = I_i$, the output current at boundary is:

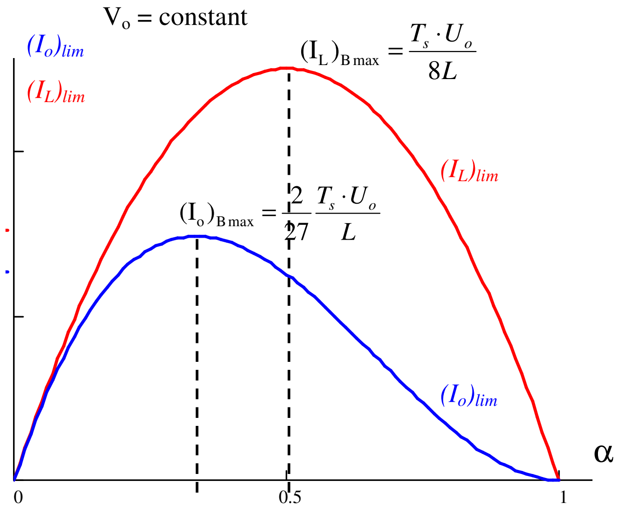


Fig. 4 The inductor and output current at boundary between continuous and discontinuous conduction

$$(I_o)_B = \frac{(I_L)_B}{2}\cdot(1-\alpha) = \frac{U_o}{2L}\cdot\alpha\cdot(1-\alpha)^2\cdot T_S \qquad (4)$$

The maximum of $(I_L)_{B\,peak}$ and $(I_L)_{B\,peak}$ is obtained for α = 0,5 and α = 0,33 respectively, as it is shown in Fig. 4.

In discontinuous conduction mode the output voltage is:

$$V_o = \frac{\alpha_1 + \alpha}{\alpha_1}\cdot V_i \qquad (5)$$

where $\alpha_1 = \frac{t_1}{T_s}$, as show in Fig. 5.

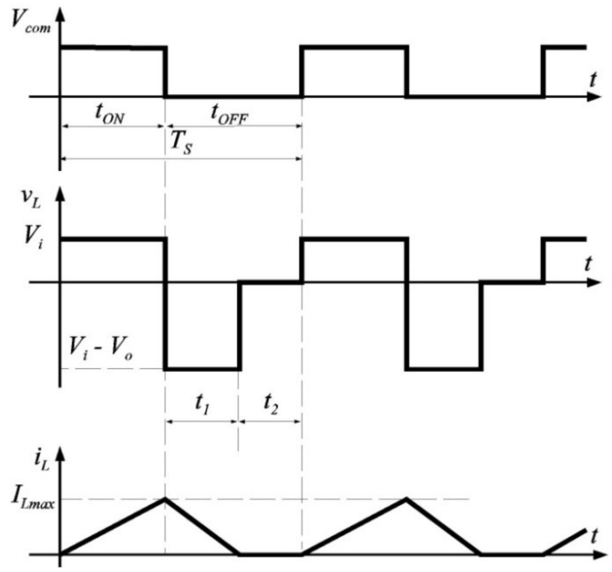


Fig. 5 Discontinuous conduction in step-up converter

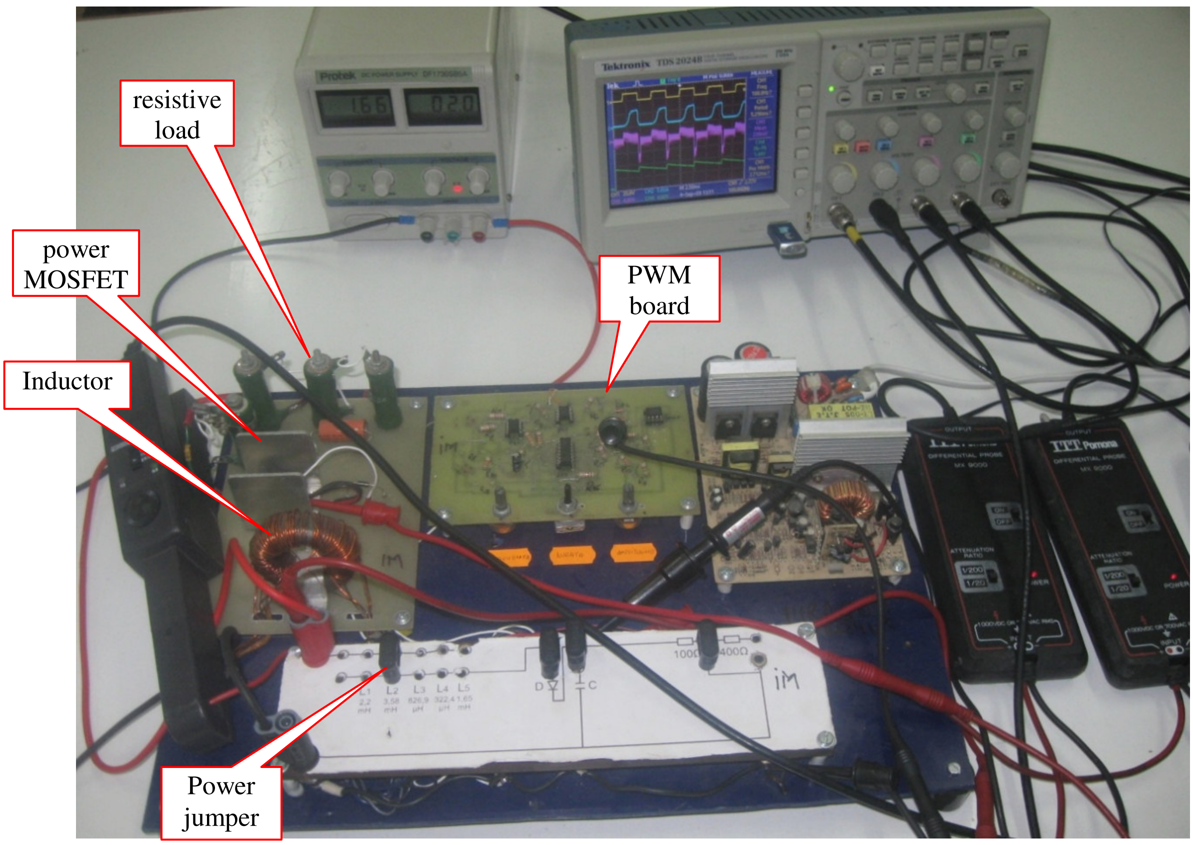


Fig. 6 The experimental arrangement

III. EXPERIMENTAL RESULTS

It is very important for the students at labwork, to understand how works this converter (presented in Fig. 6) and to observe what influence have the inductor value L, the switching frequency f_s, the duty cycle α and the output current value I_o to the converter performances.

For that we realized a step-up converter especially for power electronics laboratory. As shows in Fig. 7 the electrical schema has facilities for changing the inductor value L, the switching frequency f_s and the duty cycle α. Furthermore, they can choose to connect or not the capacitor C and/or diode D, respectively to select different values for resistive load.

Because the time of labwork is two hour and in this time the students must study many things it is necessary the time spent for all change in electrical schema to be as short is possible. For that we use the power jumpers (Fig. 6) to make this change in schema.

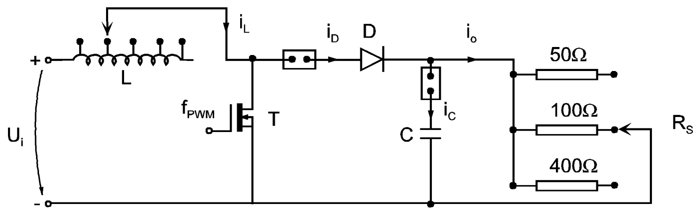


Fig. 7 Experimental schema of the step-up converter

The PWM board block diagram, illustrated in Fig. 8, permits adjust the both switching frequency by sawtooth voltage generator (in range of 130 Hz to 1,4 kHz) and the switch duty cycle by level at control voltage (in range of 0 to 1). The switch control signals (on or off) is generated by comparing a signal level control voltage $v_{control}$ with a sawtooth voltage v_{st} (repetitive waveform).

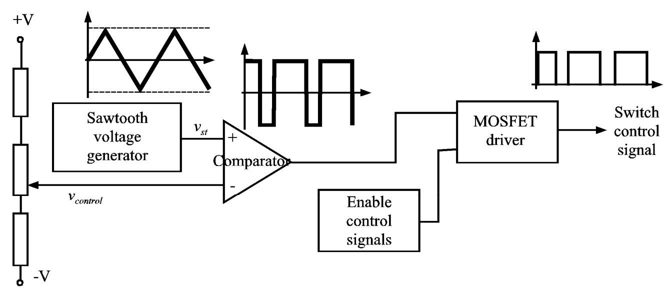
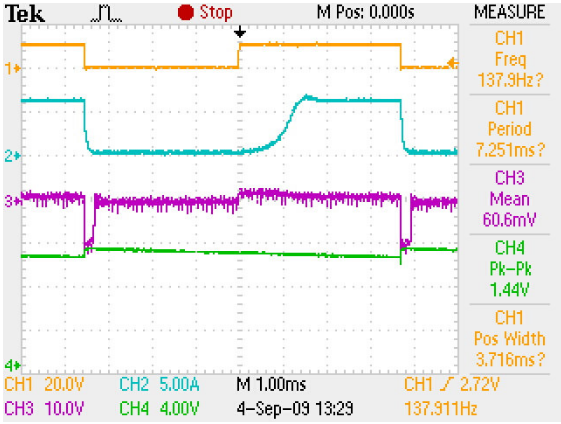


Fig. 8 PWM board block diagram

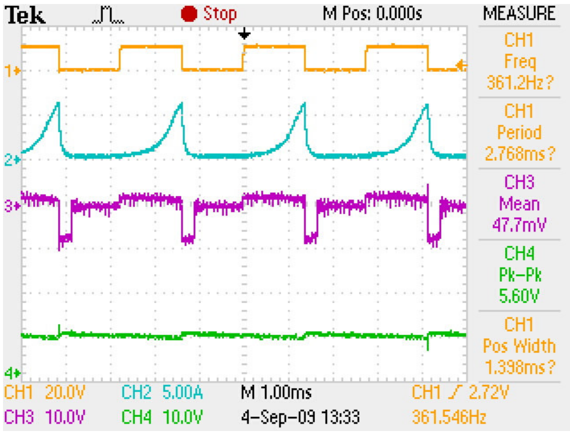
In Fig. 9 we can observe the inductor current i_L (waveform Ch. 2) at different switching frequency. In this test, the students can observe how the current peak decreases with switching frequency increases. In Fig. 8a the inductor current is limited at 6A by input source.

Also it can study the influence of the switching frequency f_s and the load R to output voltage ripple (waveform Ch. 4).

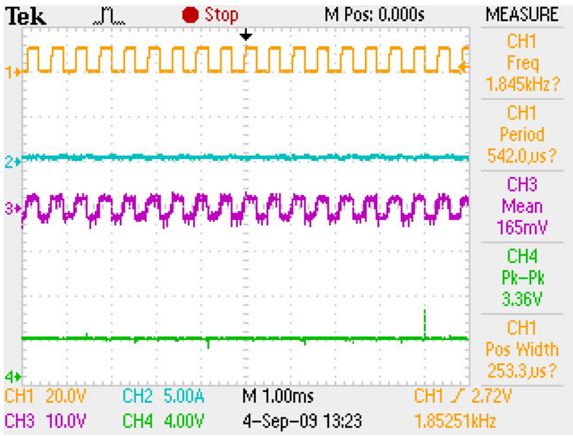
The output voltage ripple decreases with increase of switching frequency. We can see in Fig. 9 that if the switching frequency increases and the load resistance is constant the ripple output voltage is reduced considerable.



a)



b)



c)

Fig. 9 v_{com}, i_L, v_L and v_o waveforms at different frequency and Rs = 400 Ω

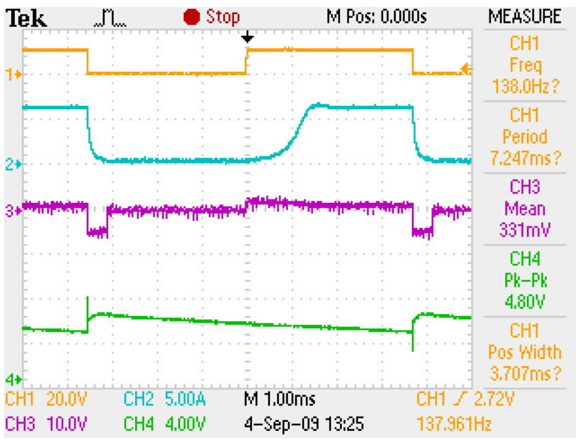
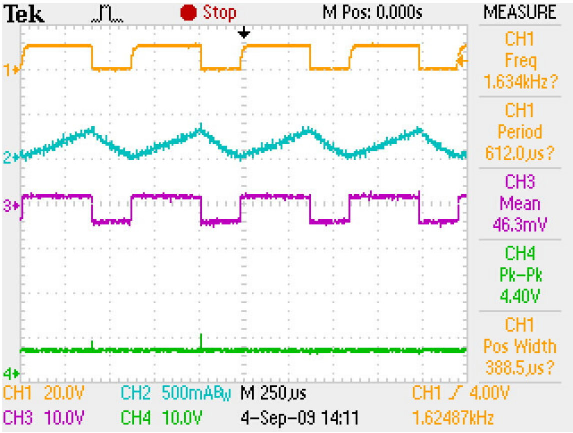
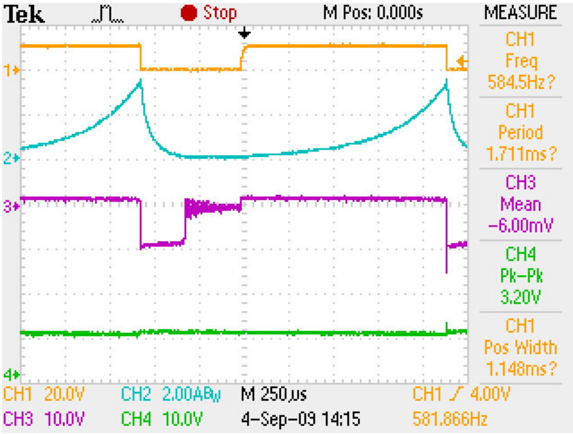


Fig. 10 The waveforms with Rs = 100 Ω

But, the output voltage ripple decreases too with increase of output current and the switching frequency constant. We can observe that, if we see Fig. 9a (Rs = 400 Ω) and Fig. 10 (Rs = 100 Ω).



a)



b)

Fig. 11 Waveforms for continuous and discontinuous conduction

A significant thing that students must understand is continuous and discontinuous conduction of the converter. As shows in Fig. 11a the converter works in continuous conduction (the inductor current illustrated in Fig. 11a - Ch. 2, flows continuously) and if the switching frequency is decrease the conduction will become discontinuous (Fig.11b).

But conduction of the converter will become discontinuous too, if the converter output current increases.

With power jumper the students can view very easy to oscilloscope display what effect have the capacitor to the waveforms. Fig. 12 shows the waveforms without capacitor C and we can see the converter output tension spike when the transistor MSFET is turned OFF because of inductor energy.

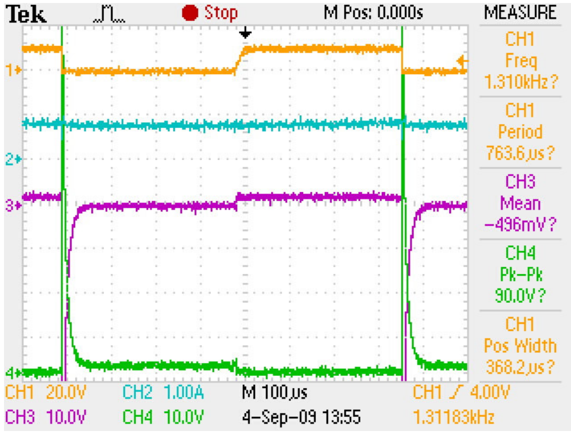


Fig. 12 Waveforms without capacitor *C*

IV. CONCLUSION

This paper presents a step up converter used in power electronics laboratory. This converter is realized by authors and it was designed especially for this activity. The main features of this converter are:

- permit very easy to adjust different parameters, like: f_s, α, L, R;
- aids the students to understand how work this converter (because they can observe any current or voltage of the converter with the oscilloscope);
- reduce the time to make the changes in converter schema (adjust value of inductor *L* or resistance load, connect or disconnect the filter *L* and/or *C*) using the power jumpers as show in Fig. 6.

REFERENCES

[1] N. Mohan, T.M. Underland, W.P. Robbins. Power electronics: Converters, Applications and Design, John Willey & Sons, New York, 2nd Edition, ISBN 0-471-58408-8, 1995.

[2] V. Popescu. Electronică de putere, Editura de Vest, Timişoara, ISBN 973-36-0306-6, 1998.

[3] M. Raţă, G. Raţă, I. Graur, D.L. Milici, "An Efficient Solution of the Step-down Converter for Students Teaching", ELEKTRONIKA IR ELEKTROTECHNIKA, no. 4 (92), pp. 77-80, ISSN: 1392-1215, 2009.

[4] Heinz van der Broeck, "Students build their own Switched Mode Power Supplies or how to promote Power Electronics at Universities", Available on www.epeec.ethz.ch/pdf/broeck_epe2001.pdf

[5] V. Popescu, D. Lascu, D. Negoitescu. Convertoare de putere în comutaţie – aplicaţii, Editura de Vest, Timişoara, ISBN 973-36-0322-8, 1999.

[6] M. Raţă. Convertoare statice – Îndrumar de laborator, Editura Universităţii Suceava, 978-973-666-300-0, 2008.