Output Overvoltage in DC-DC Switching Converters in Case of Sudden Unloading

Jiri Hammerbauer
Department of Electronics and Information Technology/RICE, University of West Bohemia,
Plzen, Czech Republic
hammer@kae.zcu.cz

Milan Stork
Department of Electronics and Information Technology/RICE, University of West Bohemia,
Plzen, Czech Republic
stork@kae.zcu.cz

***Abstract* – In present time the high efficiency switching DC/DC converters, e.g. buck and boost are often used. This work describes some problems of DC-DC converters, which can occur, when the load is suddenly disconnected or simultaneous disconnection of the load and the capacitor at the output. The results were derived both by simulation but also by measurement. A special measuring system has been developed for these measurements, which enables the realization of fault conditions. Therefore, measurements were performed on 2 different types of DC-DC converters. The results of simulations and measuring are presented in the work. Error conditions usually cause an overvoltage that can damage the equipment connected to the converter. A solution how to prevent overvoltage and thus damage connected systems is also described.**

Keywords - buck converter; boost converter; inductor energy; load loss; overvoltage; protection

I. INTRODUCTION

High-efficiency switching DC / DC converters are increasingly being used today, especially for use in battery-powered devices such as telephones, laptops, solar and wind power sources, and also in the automotive industry [1-5]. DC / DC converters operate as stabilized sources, but under certain exceptional circumstances they can damage the connected system by the overvoltage.

Assume that several systems are connected to the DC-DC converter, some with low consumption, which are sensitive to overvoltage. Furthermore, assume that for some reason there will be a sudden disconnection of large loads (or at the same time also disconnection of the output capacitor) but the overvoltage sensitive load which has low consumption remains stay connected. Therefore, simulations of sudden load and output capacitor drop on buck and boost DC-DC converters were performed [6-10]. It should be noted that, unlike continuous DC power supplies, switching power supplies contain an inductance in which energy is stored, which can cause a sudden overvoltage on output when a rapid decrease in load occurred.

A number of works have been devoted to the simulation of DC-DC converters and therefore the simulations are not described in detail here, only the results are given [11-15]. Simulations were performed in SPICE and partly confirmed by Simulink. The results were also verified by measurements on 2 types of real DC-DC converters.

II. SIMULATION RESULTS

This section presents the results of simulations of DC-DC converters of the buck and boost type. The simulations were performed assuming that the transducers were set to a steady state, loaded at the output, and the inductor current was continuous (continuous current mode). Then, firstly, the load and then, secondly, also the capacitor at the output was suddenly disconnected. In Fig. 1 is a simulation of a sudden load change in a DC-DC buck (Step-down) converter with normal output voltage 5 V is shown (Other converter parameters: Input voltage 15 V, L = 250 μH, coil resistance = 0.1 Ω, output capacitor value = 1 μF, capacitor equivalent series resistance (ESR) =.0.02 Ω, switching frequency 100 kHz). At 0.12 ms, the load resistor is changed according (1):

$$R_{LOAD} = \begin{cases} 20\Omega & t \in \langle 0; 0.12 \rangle \\ 800\Omega & t \in \langle 0.12; 0.17 \rangle \text{ [ms]} \\ 20\Omega & t \in \langle 0.17; \infty \rangle \end{cases} \tag{1}$$

It can be seen from Fig. 1 that the output voltage has increased to almost 6.5 V. The Fig. 2 shows the case when *R* and *C* are changed at the same time (*C* from 1μF to 0.1μF). The output voltage reached up to 16 V.

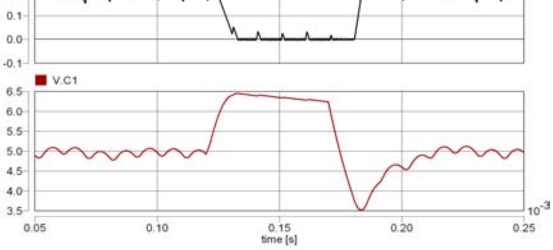

Figure 1. Spice simulation of a buck DC converter during sudden load change. Top - inductor current, bottom - output voltage

---

This work was supported by Department of Electronics and Information Technology/RICE, University of West Bohemia, Plzen, Czech Republic and by the Ministry of Education, Youth and Sports of the Czech Republic under the project OP VVV Electrical Engineering Technologies with High-Level of Embedded Intelligence, CZ.02.1.01/0.0/0.0/18_069/0009855 and by the Internal Grant Agency of University of West Bohemia in Plzen, the project SGS-2021-005.

ISBN 978-80-26-0973-0, © University of West Bohemia, 2021

2021 International Conference on Applied Electronics (AE) | 978-80-261-0973-0/21/$31.00 ©2021 10.23919/AE51540.2021.9542875

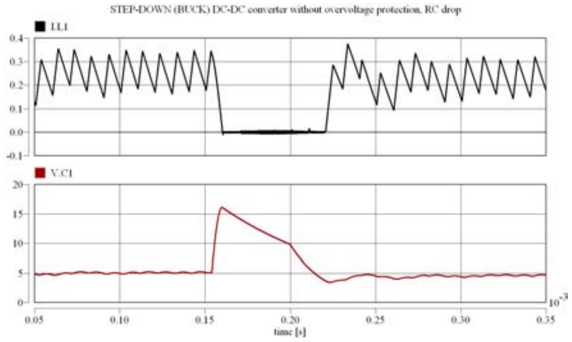

Figure 2. Spice simulation of a buck DC converter during sudden *R* and *C* drop. Top - inductor current, bottom - output voltage

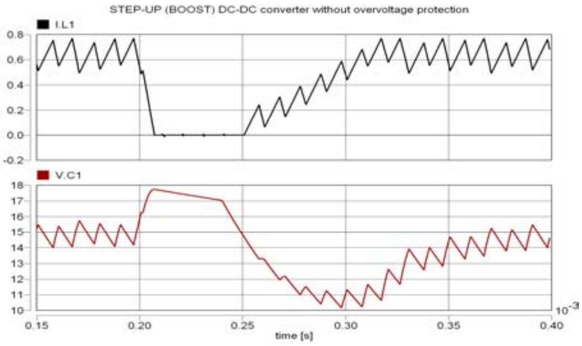

Figure 3. Spice simulation of a boost DC converter during sudden load change. Top - inductor current, bottom - output voltage

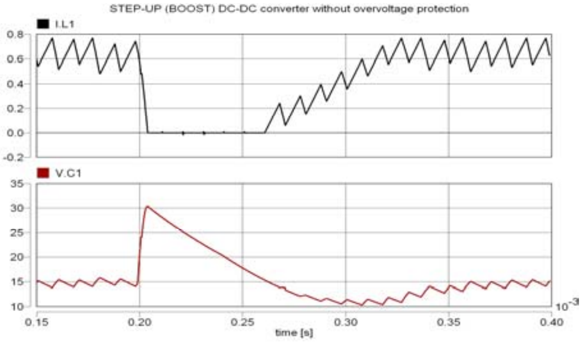

Figure 4. Spice simulation of a boost DC converter during sudden *R* and *C* drop. Top - inductor current, bottom - output voltage. The output voltage reached up to 30 V

In the next Fig. 3, there is an example of a boost (Step-up) converter simulation during load change. Normal output voltage is 15 V. (Other converter parameters: Input voltage 5 V, L = 150 µH, coil resistance = 0.1 Ω, output capacitor value = 1 µF, capacitor ESR = 0.02 Ω, switching frequency 100 kHz). At 0.2 ms, the load resistor is changed according (2):

$$R_{LOAD} = \begin{cases} 80\Omega & t \in \langle 0;0.2) \\ 900\Omega & t \in \langle 0.2;0.24) \ \text{[ms]} \\ 80\Omega & t \in \langle 0.24;\infty) \end{cases} \tag{2}$$

It can be seen from Fig. 3 that the output voltage has increased from 15 V to almost 18 V. The Fig. 4 shows the case when *R* and *C* are changed at the same time (*C* from 1µF to 0.1µF). The output voltage reached up to 30 V.

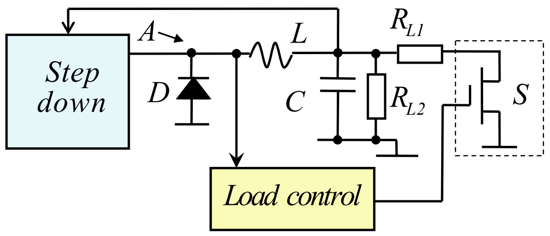

Figure 5. Simplified scheme of buck (step-down) converter with load control system for sudden R_{L1} drop

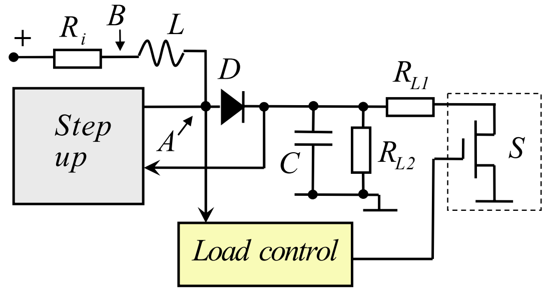

Figure 6. Simplified scheme of boost (step-up) converter with load contol system for sudden R_{L1} drop

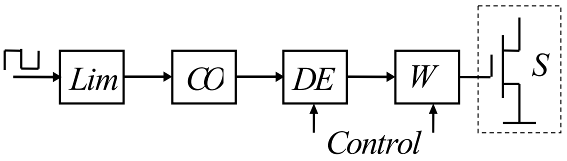

Figure 7. The Block diagram of measuring system that allows sudden shutdown of the load at the required moment. *Lim*-limiter, *CO*-counter, *DE*-delay, *W*-width, *S*-switch

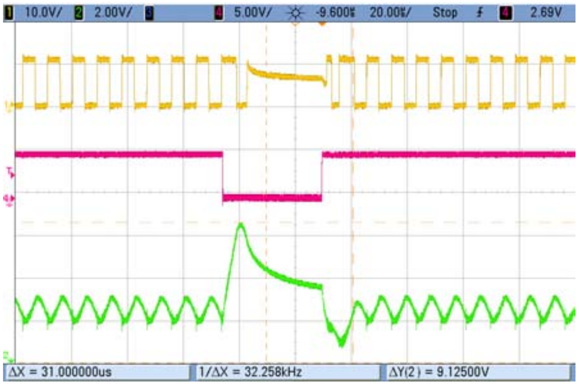

Figure 8. Oscilloscope records of a Buck DC-DC converter (12V to 5 V) during sudden load drop. From top to bottom: Inductor (measuring point A, see Fig. 5), switch control voltage (high=switch ON, low=switch OFF), Vin=12 V, output voltage (max. 9.125 V)

III. MEASUREMENT RESULTS

Fig. 5 and 6 are block diagrams of DC-DC converters supplemented by a load control system that allows the load (R_{L1}) to be periodically disconnected and connected (*S* work as a switch). The block diagram of the load control system is shown in Fig. 7. The system is connected to the inductor, sees Fig. 5 and 6 and contains a shaping circuit (*Lim*), a counter (*CO*) with the possibility of presetting a number, a circuit for setting the delay time (*DE*) and a circuit for setting the load disconnection width time (*W*). The divide number of the counter, delay unit and width unit can be set independently. It should be noted that this circuit was also used for the simultaneous dropping of the load and capacitor.

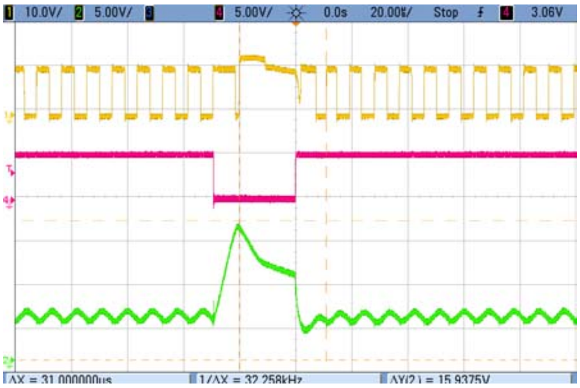

Figure 9. Oscilloscope records of a Buck DC-DC converter during sudden load resistor and output capacitor drop. From top to bottom: Inductor (measuring point A, see Fig. 5), switch control voltage (high=switch ON, low=switch OFF), output voltage. Parameters: Before RC drop R_L =5 k || 50 Ω, *C*=68 nF +2 µF, after RC drop R_L =5 k Ω, *C*=68 nF, Vin=12 V, max. Vo=15.97 V

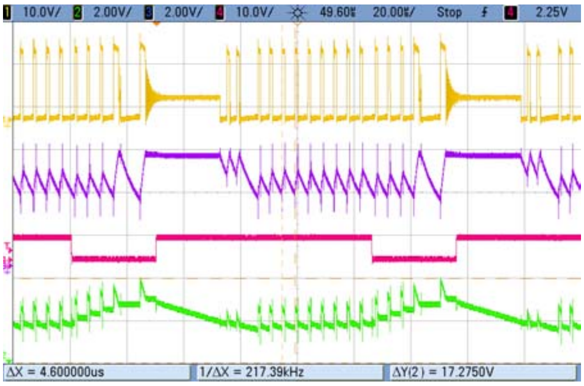

Figure 10. Example of a Boost DC-DC converter during sudden load drop. From top to bottom: Inductor (measuring point A, see Fig. 6), indirect inductor current measuring (measuring point B, see Fig. 6), switch control voltage (high=switch ON, low=switch OFF), output voltage, max. Vo=17.27 V, R_L=110 Ω (before drop), C=4.7 µF, normal: Vi=5 V, Vo=15 V

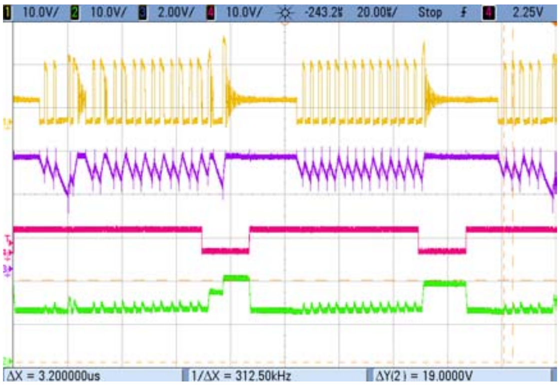

Figure 11. Example of a Boost DC-DC converter during sudden *R* and *C* drop. From top to bottom: Inductor (measuring point A, see Fig. 6), indirect inductor current measuring (measuring point B, see Fig. 6), switch control voltage (high=switch ON, low=switch OFF), output voltage, max. Vo=17.27 V, R_L=110 Ω (before drop), C=4.7 µF, normal: V_i=5 V, V_o=15 V, V_{omax}=19 V

Two DC-DC converters MC34063 (connected as buck, step-down, Fig. 3) [16] and MAX762 (boost, step-up, Fig.4) [17] were used for the measurement. The load and output capacitor were chosen so that at steady state the converters were in uninterrupted current mode. Fig. 6 and 7 are oscilloscope records for buck and boost.

IV. OVERVOLTAGE PROTECTION

This section contains options on how to prevent overvoltage at the output of the inverter in the event of a load on the load, or the capacitor. The principle is based on the addition of an external comparator and switches that are controlled by the comparator. An example of the solution is shown in Fig. 12 (for a step-down converter) and in Fig. 13 (for a step-up converter). Additional components are displayed in red. The simulation results for both types of converters are shown in Figures 14 and 15. The measurement result on the step-down converter with overvoltage protection is shown in Fig. 16

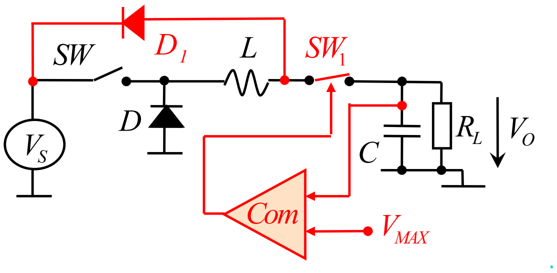

Figure 12. Simplified scheme of buck (step-down) converter with output overvoltage protection. Added components: *Com* - comparator, SW_1-switch, D_1-diode

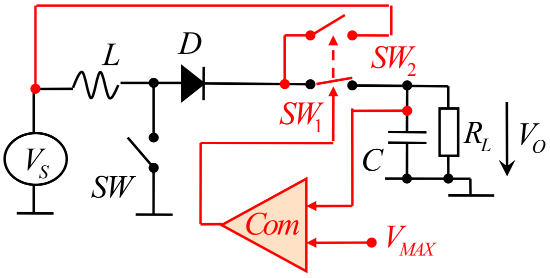

Figure 13. Simplified scheme of boost (step-up) converter with output overvoltage protection. Added components: *Com* - comparator, SW_1, SW_2 - switches

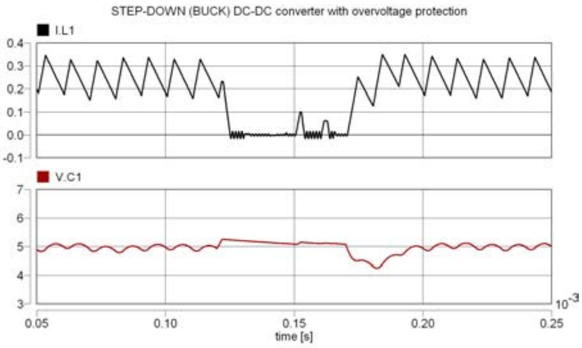

Figure 14. Spice simulation step-down with overvoltage protection during sudden *R* and *C* drop. Top - inductor current, bottom - output voltage

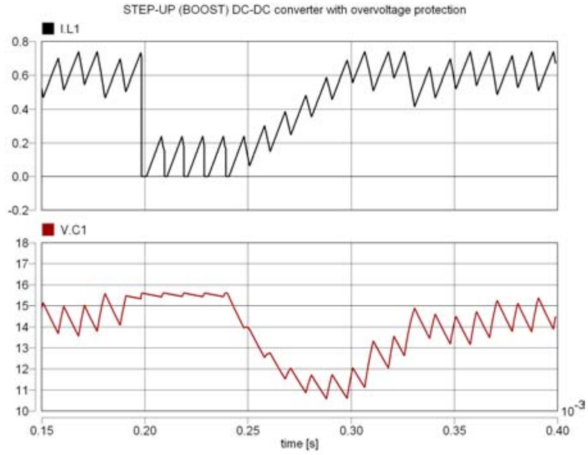

Figure 15. Spice simulation step-up with overvoltage protection during sudden *R* and *C* drop. Top - inductor current, bottom - output voltage

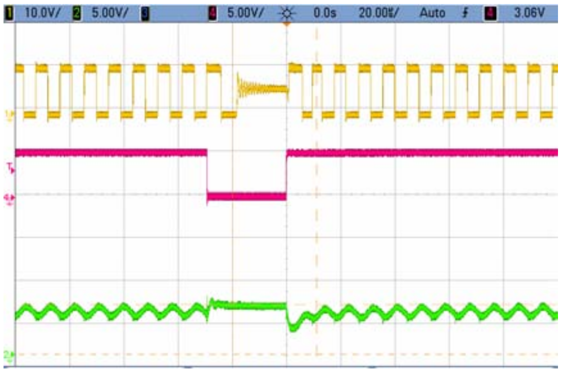

Figure 16. Oscilloscope records of a Buck DC-DC converter during sudden load resistor and output capacitor drop with overvoltage protection. From top to bottom: Inductor (measuring point A, see Fig. 3), switch control voltage (high=switch ON, low=switch OFF), output voltage

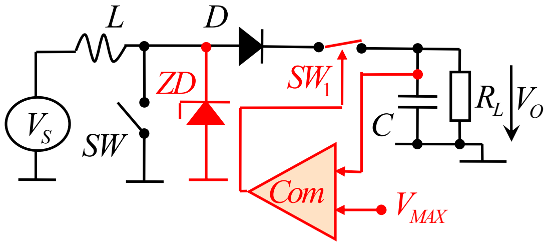

Figure 17. For converters with low power (up to several W), a Zener diode (*ZD*) can also be used to protect the output switch

For low-power converters, a Zener diode (*ZD*) can also be used to protect the switch (transistor), see Fig. 17, which prevents damage to the switch by high voltage when *R* and *C* drop out. This solution was successfully tested on a converter with IC's MAX 762.

V. CONCLUSION

In this work, the behavior of the converters during the sudden dropping of the load, or the load and the output capacitor was simulated and measured. A circuit was developed that allowed this measurement. Protective circuits have also been designed and successfully tested to protect the load from overvoltage. Although the new circuits have feedback protection, output overvoltage protection, and the device can function properly without load on the output [18], output protection can be important in several circumstances.

REFERENCES

[1] M. K. Kazimierczuk, Pulse width modulated DC/DC power converters. New York: John Wiley Publishing Press, 2008.

[2] S. Roberts, DC/DC Book of Knowledge Practical tips for the User, RECOM Engineering GmbH & Co KG, Austria 2015.

[3] B. W. Williams, Power Electronics: Devices, Drivers, Applications and Passive Components, Book, Second Edition, Educational Low-Priced Books Scheme, ELBS, 1992.

[4] M. H. Rashid, Power Electronics: Circuits, Devices and Applications, Prentice-Hall, Inc, Englewood Cliffs, Book, Second Edition, 1993.

[5] N. Munoz-Galeano, J. Lopez-Lezama & F. Villada-Duque, " Methodology for teaching the buck converter: step by step description of the design," Revista ESPACIOS, ISSN 0798 1015, Vol. 40 (Number 44) Year 2019.

[6] T. Geyer, G. Papafotiou, R. Frasca, and M. Morari, "Constrained Optimal Control of the Step-Down DC-DC Converter," IEEE Transactions on Power Electronics, 23 (5), pp. 2454–2464, 2008.

[7] B. M. Hasaneen and E. A. Mohammed, "Design and simulation of DC/DC boost converter," 12th International Middle-East Power System Conference, Aswan (Egypt), pp. 335-340, 2008.

[8] C. Restrepo, T. Konjedic, J. Calvente, M. Milanovic and R. Giral, "Fast Transitions Between Current Control Loops of the Coupled-Inductor Buck–Boost DC–DC Switching Converter," IEEE Transactions on Power Electronics, 28(8), pp. 3648-3652, 2013.

[9] C. H. Van der Broeck, R. W. De Doncker, S. A. Richter. and J. V. Bloh, "Unified Control of a Buck Converter for Wide-Load-Range Applications," IEEE Transactions on Industry Applications, 51(5), pp. 4061-4071, 2015.

[10] C. Vlad, P. Rodriguez-Ayerbe, E. Godoy and P. Lefranc, "Advanced control laws of DC-DC converters based on piecewise affine modelling. Application to a stepdown converter," IET Power Electronics, 7(6), pp. 1482–1498, 2014.

[11] A.W.Cristri, R.F.Iskandar, "Analysis and Design of Dynamic Buck Converter with Change in Value of Load Impedance," Procedia Engineering, Volume 170, pp. 398-403, 2017.

[12] U. Sengupta, "AND8117/D Understanding the Output Current Capability of DC-DC Buck Converters," ON Semiconductor, Available: http://onsemi.com, 2003.

[13] A. Barrado, R. Vazquez, A. Lazaro, E. Olías, "New DC/DC converter with low output voltage and fast transient response," Applied Power Electronics Conference and Exposition, APEC '03, 2003.

[14] K.Horng Chen, H. Wei Huang, and S. Yen Kuo,"Fast-Transient DC–DC Converter With On-Chip Compensated Error Amplifier," IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS—II: EXPRESS BRIEFS, VOL. 54, NO. 12, DECEMBER 2007.

[15] A.W.N. Husna, S.F. Siraj, M.H. Mat, "Effect of Load Variations in DC-DC Converter," 2011 Third International Conference on Computational Intelligence, Modelling & Simulation, DOI: 10.1109/CIMSim.2011.78, 2011.

[16] AN920/D, "Theory and Applications of the MC34063 and µA78S40 Switching Regulator Control Circuits," ON Semiconductor, Rev. 6, December, 2013.

[17] MAX762, Available: https://datasheets.maxim integrated. com/en/ds/MAX761-MAX762.pdf

[18] A5975D, Up to 3 A step-down switching regulator for automotive applications, Doc ID 018760 Rev 1, STMicroelectronics, 2011.