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COMPARISION OF BUCK-CONVERTER PARAMETERS QUALITY DEPENDING ON COIL SELECTION

Abstract
Buck-Converters belong to DC/DC converters group. One of the main problems during the design stage of DC/DC converter is the proper component selection. The aim of this article is to describe selection of the optimal inductor for the Buck-Converter, enabling to minimize the device output overvoltage, while getting possibly high device efficiency. In order to verify the quality parameters, author made an efficiency comparison of the buck converter, depending on used inductor. Conclusions from this paper allow for optimal selection of coils for the Buck-Converter depending on given criteria.

Key words
Buck-Converter, Step-down Converter, DC/DC Power Converter, Overvoltage, Coil selection

Introduction

Buck-Converter, known also as Step-down Converter, is the basic part of power section in many electronic devices. It is also called Step-down Converter. Such converters are commonly used in various types of power sections of modern electronic devices, such as notebooks or smartphones. One can find in literature two topologies of Step-down Converters: synchronous and nonsynchronous [2]. The synchronous converter has an additional switching key in parallel branch. In that case the transistors work complementary what means when one transistor is switched on, the second one is switched off and conversely. However, due to existence of gate-source capacity, it is needed to include additional dead time, necessary for proper switching control. Often, however, nonsynchronous Step-down Converters are used.

What is more, Buck-Converter is a part of buck family. In this group one can find: buck, buck-boost and buck-boost-buck Converters [1]. Buck-Converters work in continuous and discontinuous mode. Generally Buck-Converter is used to reduce the input voltage. However this converter can adjust output voltage range from zero to the input voltage value. The main impact on work of this device has proper selection of elements in particular coil, capacitor and two switches: diode and transistor. Proper selection is understood by small size and improving quality of Buck-Converter. The most important characteristics of the buck converter are input and output voltage, nominal current and switching frequency. It is also important to define the quality requirements regarding tolerance to voltage and output current ripples [3]-[5]. The designer must also pay attention to economic factors, such as obtaining a possibly small size of the converter, high efficiency and low prices.

In this article author presents research results of coil selection impact on mentioned parameters quality of Buck-Converter. This is as a development of considerations made in [6]. In the literature one can find theoretical thesis about work of Buck-Converter. In this paper author included only practical tests to check real work of Buck-Converter with different inductors (in figure 1 marked as L1) and their influence on efficiency and overvoltage.

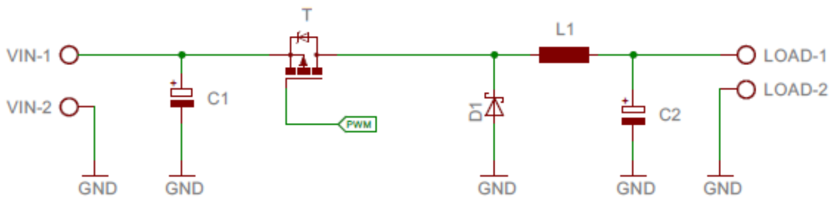

Fig.1. Step-down Converter circuit diagram. L_1 – tested coil, C_1,C_2 – capacitors, T – MOSFET transistor, D_1 – Schottky diode, Load – resistor, PWM – Pulse-Width Modulation
Source: Author's

Impact of coil selection on size and price of Buck-Converter

In this thesis author analysed work of Buck-Converter with six different inductor models: solenoid (wounded copper wire without any core) as a reference and five inductors with core. Author used few core coil types: DTP, DTMSS, SMD and two bobbin coils. All used coils have the same inductance 330 µH but different core materials, shapes and physical parameters as shown below in figure 2.

Fig. 2. Different coil types used in Buck-Converter research, from left: air coil, DTMSS coil, bigger bobbin coil, DTP coil, smaller bobbin coil and SMD coil
Source: Author's

Table 1 presents dimensions and prices of tested inductors (shown in figure 2), which affect the economic aspect. All inductors have different shapes as shown in figure 2, so occupied space in table 1 is an approximate value. The air coil was a reference inductor, which is free of the core influence.

Table 1. Coil dimensions and prices

Coil symbol	Height [mm]	Thickness [mm]	Outside diameter [mm]	Occupied space [cm^3]	Price [PLN]
Solenoid	34	8	34	9.3	7.00
DTMSS-27/0,33/2,0	27	15	27	10.9	14.00
DSz-20/330/6,3	18	20	20	5.7	4.00
DTP-17,5/0,33/2,8	21	9	21	4.0	4.20
DSz-14/330/2,2-V	15	14	14	2.3	2.50
DSMD-10/330/0,5	5.4	9	10	0.3	2.00

Source: http://www.feryster.com.pl/polski/index.php?lang=pl.

The graphs in this paper uses the following shortcuts:

- S – solenoid (without core),
- DTMSS – DTMSS-27 / 0.33 / 2.0 (DTMSS-type reactor core type RTMSS),
- DSz20 – coil DSz-20/330 / 6.3 (bigger coil of DSz type with core type RSZ),
- DTP – coil DTP-17.5 / 0.33 / 2.8 (DTP-type coil with core type RTP),
- DSz14 – coil DSz-14/330 / 2.2-V (smaller coil of DSz type with core type RSZ),
- SMD – coil DSMD-10/330 / 0.5 (inductor SMD with ferrite core Ni-Zn RSMD E6H).

The use of an appropriate ferromagnetic core increases the self-inductance of the coil, so that you can get smaller sizes coils similar electrical properties as solenoid [10]. The size of the elements is important for designing printed circuit boards for small size devices. While analysing economic factors the most optimal in terms of size and price is SMD coil. In contrast, the biggest and the most expensive is DTMSS coil. DTP coil is widely used in Buck-Converters but as one can see is neither the cheapest nor the smallest one. Another idea for achieving smaller device size is presented in [7]. This article can help to improve idea of using two inductors instead of one coil in classic Buck-Converters.

To show electrical parameters practical tests were made. Founded test scenarios were implemented using logic analyser controlling work of converter gating transistor and adjustable power supply, which was setting input voltage. With the help of measuring equipment, which included a digital oscilloscope and digital meters, author made practical measurements, in order to investigate the effect of inductor selection on the device parameters.

In this article the following shortcuts are used:
η - efficiency [%]
f – transistor switching frequency [kHz]
I – Buck-Converter input current [A]
V_{GS} – gate-source transistor voltage [V]
V_{out} – Buck-Converter output voltage [V]
V_{max} – maximum overvoltage amplitude [V]
V_{min} – minimum overvoltage amplitude [V]

Impact of coil selection on efficiency in Buck-Converter

To show the impact of coil selection on tested device efficiency, the following tests were made. Figure 3a shows the efficiency changes as a function of current for all analysed coils. Measurements were made for following current values: 0.5 A, 1 A, 1.5 A and 2 A, the frequency of 20 kHz and a duty cycle of 50%, with a load of 5 Ω. Figure 3b shows the efficiency changes as a function of frequency. The author chose load value 10 Ω, input current of 0.5 A, duty cycle of 50% and frequency measurement values at: 20 kHz, 50 kHz, 100 kHz, 200 kHz, 300 kHz and 500 kHz.

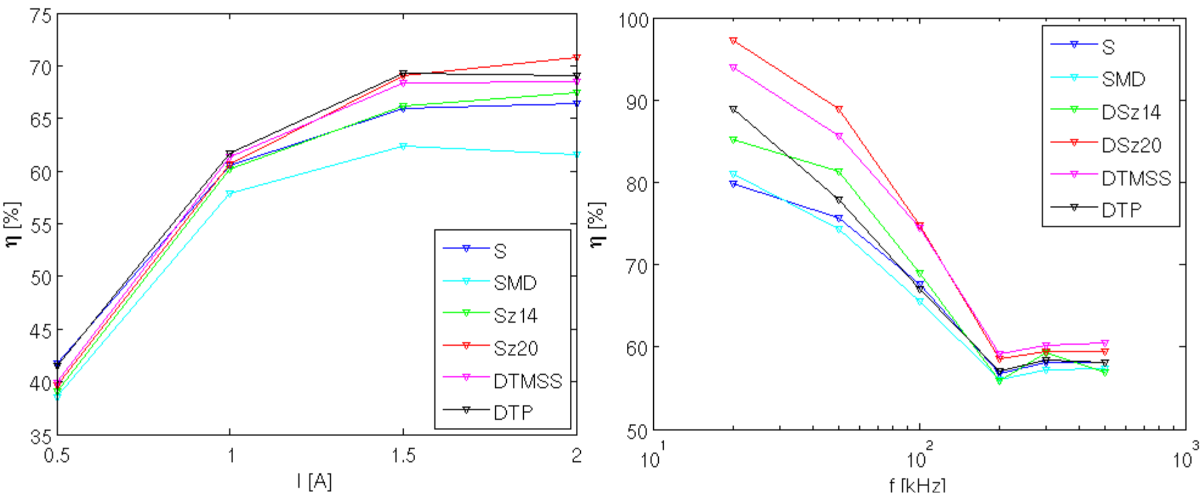

Fig.3. Efficiency changes: a) as a current function with 10 Ω load, b) as a frequency function with 5 Ω load, where η – efficiency [%]

Source: Author's

From figure 3a one can see that with the current also increases efficiency. It also can be seen that the greatest efficiency in analysed current range are bobbin coil DSz-20, DTP and DTMSS. The lowest efficiency was achieved for the SMD coil. Figure 3b reflecting the efficiency evolution as a function of frequency, confirms earlier findings that a significant difference in the coil selection is noticeable for frequencies up to about 100 kHz. As before, the highest efficiency was obtained for bobbin coil type DSz-20, and the lowest for the solenoid and the SMD coil.

The following figures illustrate the efficiency changes as a function of frequency for the resistance load of 10 Ω, input current 0.9 A and duty cycle of 75% (figure 4a) and the load resistance of 5 Ω, the input current 0.9 A and duty cycle of 75% (figure 4b). In order to maintain transparency and for analysis used three selected coils: solenoid, bobbin DSz-20 and SMD coil, which had an average, the largest and the smallest efficiency. The frequency in all graphs is shown in logarithmic scale. Measurement points at graphs form figures 4a and 4b were selected for frequency values equal 10 kHz, 20 kHz, 30 kHz, 50kHz, 75 kHz, 100 kHz, 150 kHz and 200 kHz and 500 kHz.

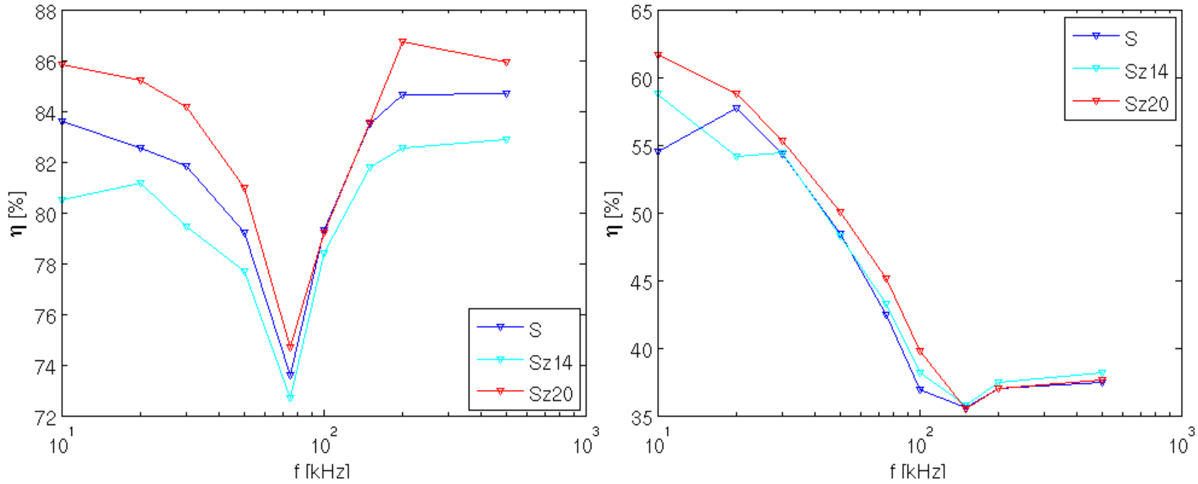

Fig.4. Efficiency changes as a frequency function with load: a) 10 Ω, b) 5 Ω, *Source: Author's*

Figures 4a and 4b show the efficiency in frequency function for the same currents and various load resistances. In Figure 4b efficiency is relatively lower comparing to the efficiency from Figure 4a, due to lower input voltage, and thus coupled with it voltage V_{GS}, which is required to achieve the same input current. In Figure 4a one can see a significant drop of efficiency for switching frequency of 75 kHz. Figure 4b shows that the minimum efficiency occurs at a frequency of 200 kHz. Change of the minimum efficiency point is dependent on both current and duty cycle. This phenomenon occurs regardless of the type of coil used in the inverter and is connected with the resonance [7].

Impact of coil selection on overvoltage in Buck-Converter

One of the most important features that define the quality of the output voltage of Step-down converter is output voltage peaks values. Overvoltage has negative impact on device work and may cause faster destruction and affect on electromagnetic compatibility. This test was designed to check the effect of coil selection on output voltage peaks depending on the frequency and current. Presented test results refer to the converter shown in Figure 1.

The first analyse was made just for solenoid which does not have core influence and can be used as the reference inductor. In figure 5a one can see output voltage changes in function of time which coming from oscilloscope measurements. Comparison was made for two current values of 0.5 A and 1 A. In figure 5b author presents output voltage signal for all tested coils in a function of time. The signals were observed for switching frequency of 20 kHz, duty cycle of 50 % and Buck-Converter input current equal 0.5 A.

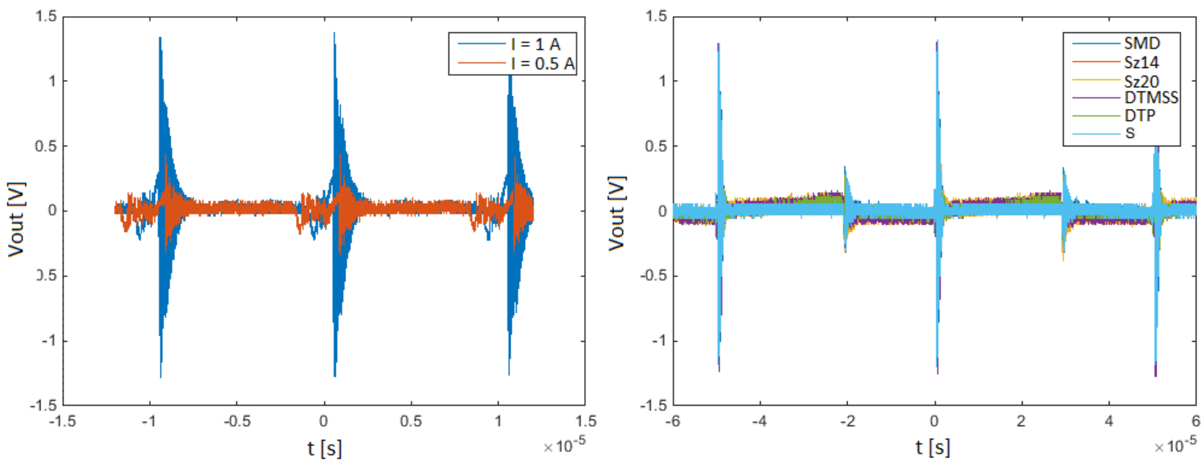

Fig. 5. Output voltage time changes a) for different current values with the usage of solenoid, b) for different coils
Source: Author's

Analysing figure 5a one can see the dependence of voltage peaks from current value. For less current value the biggest voltage peaks appear with delay. It can be also seen that bigger current value causes elongation of transient state. Size of overvoltage will be discussed in the following paragraphs. In graph from figure 5b one can see that coil selection affects on overvoltage amplitude and the time of overvoltage occurrence. To check differences between overvoltage peaks the following analysis was made.

The below measurements were made for frequency equal 100 kHz. Graphs from figures 6 (a and b) show minimum and maximum voltage changes in function of input current for duty cycle 50%. Measurements were made for current values of 0.2 A, 0.4 A, 0.8 A, 1 A and 1.2 A.

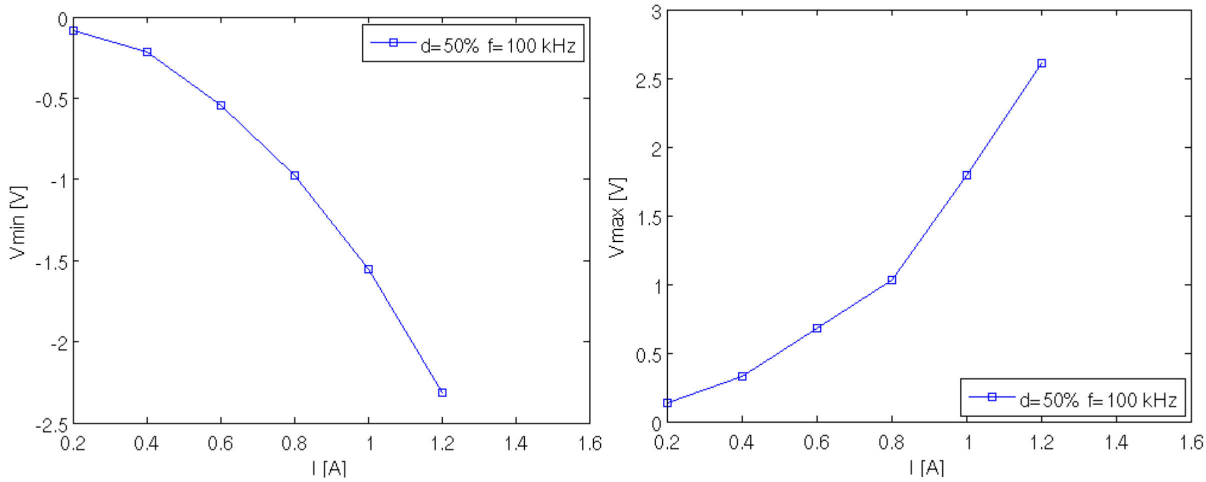

Fig. 6. Output voltage peaks for different currents with the usage of solenoid, for a) minimum voltage peaks, b) maximum voltage peaks
Source: Author's

Graphs in figures 7 (a and b) show minimum and maximum voltage changes in function of input current for duty cycle 75%. Measurements were made for current values of 0.4 A, 0.8 A and 1.2 A.

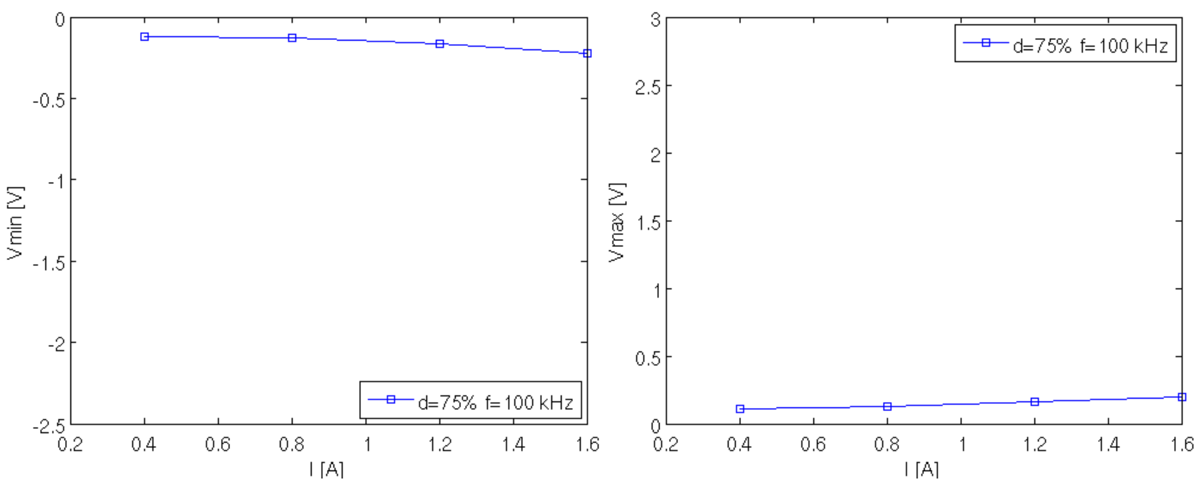

Fig. 7. Output voltage peaks for different currents with the usage of solenoid, for a) minimum voltage peaks, b) maximum voltage peaks
Source: Author's

Analysing the graphs above (in figures 6a, b and 7a, b) it can be concluded that the increase of input current, significantly floats on the value of the output voltage peaks, which is particularly visible to the duty cycle equal 50%. Moreover, the load voltage peaks increase exponentially during current changes. In the case of the duty cycle of 75% overvoltage changes are less noticeable, but the trend is the same. To compare overvoltage size, above figures have the same range of y-axis.

Figures 8a and 8b shows the output voltage amplitude changes as a function of frequency. Due to the asymmetry of voltage peaks, the author made a distinction between positive and negative peaks. Measurement points were selected for frequency values equal 20 kHz, 50kHz, 100 kHz and 200 kHz.

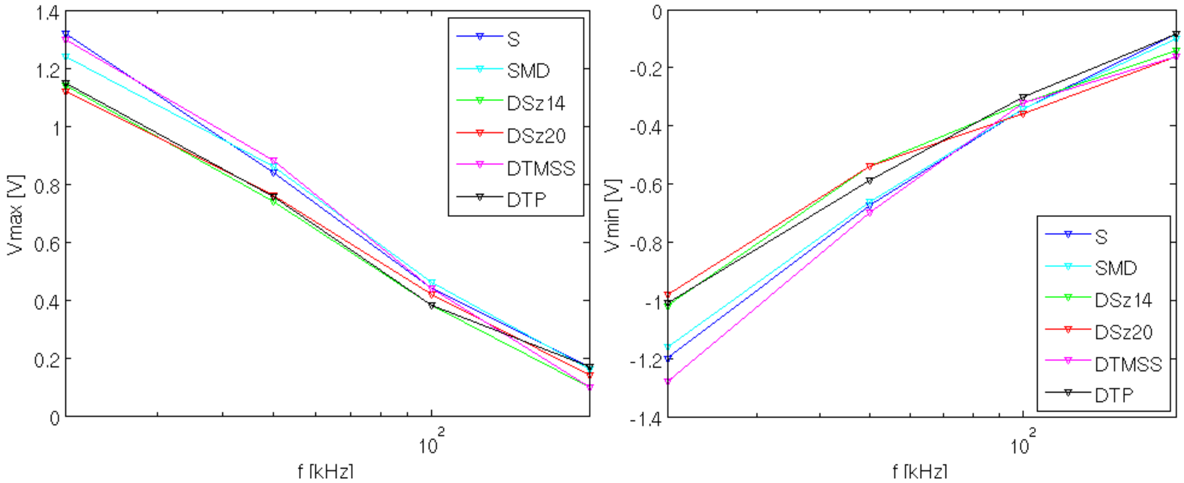

Fig.8. Peak values changes: a) maximum, b) minimum, as a function of frequency for input current of 0.5 A, *Source: Author's*

According to theoretical considerations from [5], [11] - [13], for the lower frequencies are voltage peaks have bigger values. In the case of a positive voltage peaks the author measured values from about 1.1 to 1.35 V, while in the case of a negative peak, recorded values from -1 to -1.3 Volts. For the lower frequency the smallest overvoltage occurred for the bobbin coil type DSz-20 while the biggest overvoltage appeared for solenoid and DTMSS coil.

Figure 9a and 9b show the output voltage peaks for current equal 1 A and duty cycle of 50%. For this case to maintain the parameters of voltage and current, the measurements were made only for two frequency values: 50 kHz and 100 kHz.

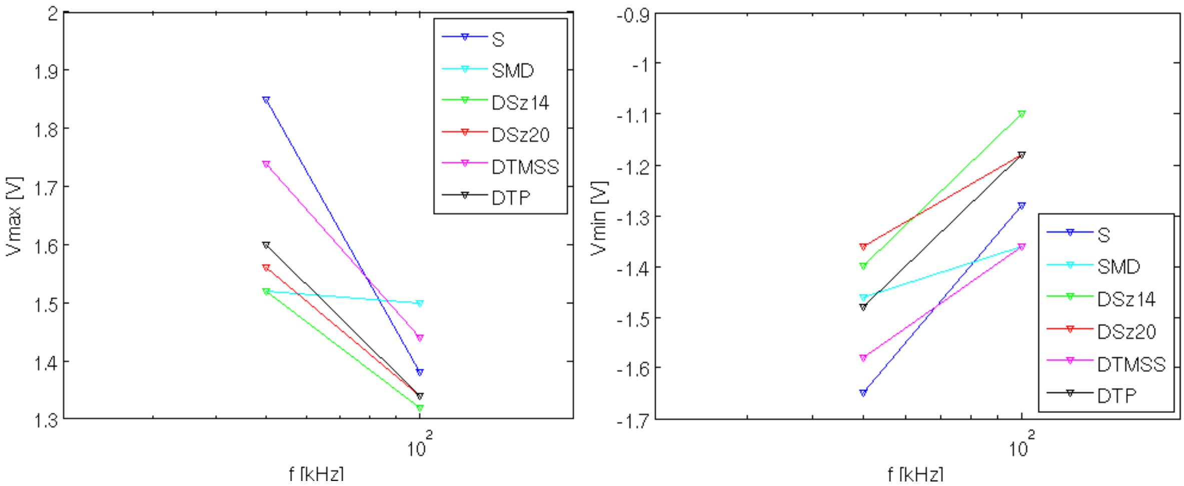

Fig.9. Peak values changes: a) maximum, b) minimum, as a function of frequency for input current of 1 A
Source: Author's

Analyzing the figures 9a and 9b one can see that both positive and negative overvoltage the worst results were obtained for the solenoid, while the best results for bobbin coils: DSz-14 and DSz-20. Despite the limited number of measurement results, this study gives important information, because it allows observing the scale of overvoltage growth during current increase. In this study, appropriate coil selection affects on the device quality in terms of overvoltage for lower frequencies. With increasing frequency, these differences become less visible.

Summary and conclusions

The article presents studies results of using different inductor types impact on Buck-Converter parameters. All presented results come from real tests. Author obtained the influence of coil selection on output voltage characteristics and efficiency changes, depending on frequency and current. This paper also shows how the proper coil selection helps to reduce appearing overvoltage on the output of the Buck-Converter.

It is hard to indicate just one coil that gives the best results. The first important problem is to reduce size of power supply section. Clients usually want to have possibly cheap and small devices. Designers try to make devices with high efficiency and limited overvoltage. To minimize converter size and reduce price, author recommend using SMD coil. This coil is noticeably cheaper than other coils and takes the smallest surface. In the other hand the best result, in the case of overvoltage, we can get using bigger bobbin coil (DSz-20). This bobbin coil also allows achieving the biggest efficiency and has medium size. Presented tests can be used during projecting Step-down Converters.

References

[1] Wu TH., The origin of converters, Future Energy Electronics Conference (IFEEC), 2013 1st International, pp. 611-617.

[2] Nowakowski R., Tang N., Efficiency of synchronous versus nonsynchronous buck converters, Texas Instruments Inc., 2009 [Online]. Available: http://www.ti.com/lit/an/slyt358/slyt358.pdf

[3] Nowak M., Barlik R., Poradnik inżyniera energoelektronika, Wydawnictwo Naukowo-Techniczne, Warszawa 1998, pp. 160-168.

[4] Janke W., Techniki opisu impulsowych przetwornic napięcia stałego, Przegląd Elektrotechniczny, nr. 11b, 2012, pp. 5-10.

[5] Górecki, K. Zarębski, J., Wpływ doboru elementów półprzewodnikowych na charakterystyki przetwornicy buck, Elektronika: konstrukcje, technologie, zastosowania, Vol. 52, nr. 8, 2011, pp. 124-127.

[6] Pragłowska-Ryłko N., Analiza wpływu doboru cewki na pracę przetwornicy DC/DC obniżającej napięcie, Elektronika: konstrukcje, technologie, zastosowania, nr. 5, 2015, pp. 50-52.

[7] Amini M.R., Farzanehfard H., Switched resonator DC/DC converter with a single switch and small inductors, Power Electronics, IET (Volume:7 , Issue: 6), 2014, pp. 1331-1339.

[8] Milashevski I., Galkin I., Tetervenok O., Assessment of Buck Converter Powered by Current or Voltage Sources for LEDs Luminary, Electronics Conference (BEC), 2012 13th Biennial Baltic, pp. 239-242.

[9] Liu S., Liu J., Yang Y., Zhong J., Design of Intrinsically Safe Buck DC/DC Converters, Electrical Machines and Systems, Vol. 2, ICEMS 2005 China, pp. 1327-1331.

[10] Górecki K., Detka K., Wpływ doboru rdzenia dławika na nieizotermiczne charakterystyki przetwornicy buck, Elektronika: konstrukcje, technologie, zastosowania, Vol. 52, nr 10, 2011, pp. 76-78.

[11] Górecki K., Zarębski J., Pomiary elementów i układów elektronicznych, Wyd. Tekst Sp. z o.o., Bydgoszcz, 2009

[12] Górecki K., Stepowicz W.J.: Influence of Inductor Models on the Characteristics of the Buck and Boost Converters. XXX International Conference on Fundamentals of Electrotechnics and Circuit Theory IC-SPETO 2007, Ustroń, 2007, pp. 71.

[13] Górecki K., Stepowicz W.J., Comparison of Inductor Models Used in Analysis of the Buck and Boost Converters, Informacije MIDEM, Vol. 38, No.1, 2008, pp. 20-25.