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Selection of Inductor and Capacitor for Buck Converter using Design Equations Comparison

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A type of DC-DC step down converter is a Buck converter, they are used in power supplies, computers, electric tools, cars and many other electronic devices. Their purpose is to step down one DC voltage to another DC voltage as efficiently as possible. This efficiency can only be obtained by understanding the fundamentals of the converter and selecting the correct components when designing a converter for an application. The two main components in the converter are the inductor and output capacitor. Various approaches have been taken to find optimum values for these components. This paper will look at some of these methods to assess how appropriate they are in terms of converting the DC voltage to a reduced level through modelling the circuits with MATLAB with values obtained for the inductor and output capacitor from these methods.

Keywords: Inductor, Capacitor, Buck Converter, MATLAB

Introduction

A Buck converter consists of a MOSFET (switch), inductor, diode, output capacitor and load. It is a basic Switch Mode Power Supply (SMPS) that is both unidirectional and non-isolated, that is the input and output grounds are connected, and the output polarity is the same as the input. The inductor and capacitor are used to control, store and transfer energy from the input to output depending on the state of the switch, either on or off. Control of the output voltage is achieved through the switching of the MOSFET. For the Buck converter to operate to a specific set of output parameters the inductor and capacitor must be sized correctly. If these are correct the circuit will give correct outputs in terms of load voltage ripple and inductor current ripple.

Component selection calculations

A variety of sources were examined¹⁻⁹ and were found to have different ways to calculate the critical components, the inductor and output capacitor. The basic circuit diagram of a Buck converter is shown in Figure 1. Another important consideration is the duty cycle, the time the switch (MOSFET) in the converter is on compared to off¹⁰,

$$\text{Duty Cycle} = V_o/V_i \quad \dots (1)$$

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Before calculations for the inductor and capacitor can be performed, the circuit must be based around a set of specifications. The circuits can then be tested with the inductors and capacitors calculated to see if they meet the required specifications. The duty cycle (D) of the p-channel MOSFET is set on 66.6% to give an output voltage of 12V, based on equation (1). The requirements for this circuit are Input

Input Voltage (Vi)	18V
Output Voltage (Vo)	12V
Frequency (f)	32000Hz
Output Current (Io)	4.17A
Output Power (P)	50W
Inductor Ripple Current (Δi)	1.25A (30%)
Output Voltage Ripple (Δv)	0.12v (1%)
Duty Cycle	66.6%

With these figures the critical inductance can be calculated, this is the minimum inductor value required to keep the buck converter in Continuous Conduction Mode, this value was calculated using¹¹.

$$L = 14.5\mu F$$

Figure 2 shows the Simulink model that was used for testing the inductor and capacitor values calculated from the equations in Sources¹⁻⁹. A load resistor of 2.8 Ohms is included to give an output

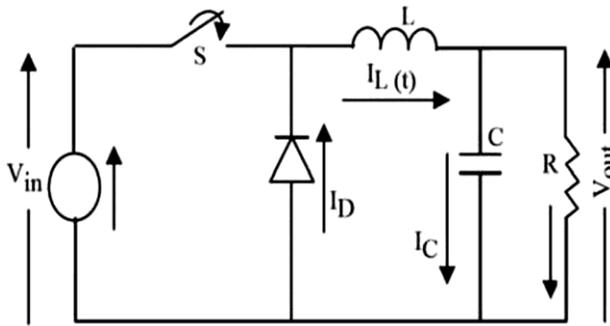


Fig. 1 — Basic circuit of a buck converter

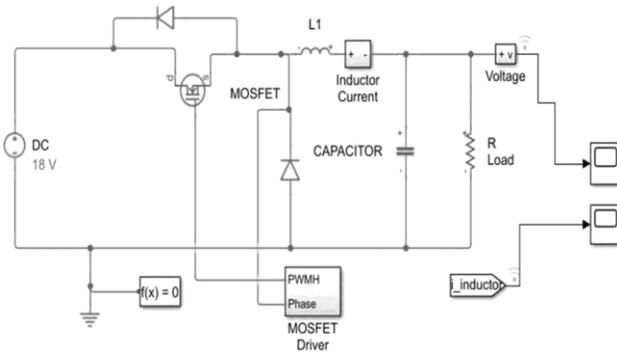


Fig. 2 — Simulink circuit used for testing

power of 50W. The inductor, L1, and capacitor, CAPACITOR, are the values which were substituted with those calculated.

Results from Calculations

From the sources’ values for the inductor and capacitor were calculated. Apart from Source 4 which had an inductor value of 50uH, the other eight values were 100uH. The capacitor values varied over a much greater range. From source 1 to 9 respectively the values were 15, 10, 122, 813, 319, 82, 21, 117 and 41uF. Before reaching steady state source 2, the lowest capacitor value, 10uF, with the 100uH inductor, had a peak to peak values of 5.142A and 13.34V. Source 5 the highest capacitor value, 319uF, with the 100uH inductor had peak to peak values of 21.78A and 19.72V. Source 4 with the 50uH inductor and 813uF capacitor had 50.59A and 20.62V peak to peak values. After reaching steady state the values of the load voltage, its ripple, and the inductor current, and its ripple are shown in Table 1. This shows that by keeping the inductor value the same but changing the capacitor value has no real effect on the inductor current ripple. It also shows that by increasing the size of the capacitor the amount of voltage ripple on the load for the given inductor is reduced. The results from source 4 show that the inductor is far too small to

Table 1 — Load ripple voltage and inductor ripple current from simulations.

Source	Load Voltage (V)	Load Voltage Ripple (V)	Load Voltage Ripple (%)	Inductor Current (A)	Inductor Current Ripple (A)	Inductor Current Ripple (%)
1	11.65	0.34	2.92	4.083	1.326	32.48
2	11.69	0.51	4.36	4.080	1.333	32.67
3	11.59	0.04	0.35	4.088	1.320	32.29
4	11.58	0.02	0.17	4.161	2.643	63.52
5	11.58	0.02	0.17	4.099	1.322	32.25
6	11.59	0.07	0.60	4.091	1.318	32.22
7	11.64	0.24	2.06	4.100	1.308	31.90
8	11.59	0.05	0.43	4.071	1.333	31.74
9	11.61	0.12	1.03	4.072	1.288	31.63

provide the required inductor ripple current, and that the capacitor values in sources 1,2 and 7 are too small to provide the required voltage ripple. Sources 3,5,6,8 and 9 all give acceptable voltage ripple with a capacitor range of 41uF to 319uF, but the inductor ripple is just over the 30% specified with the inductor at 100uH. Since increasing the inductor value decreases the inductor current ripple a 110uH inductor was substituted for the 100uH. A capacitor of 45uF was used as this was found to give acceptable voltage ripple in the previous calculations. After simulating with these two components it was found to give load voltage ripple under 1% and inductor current ripple under 30%. Data sheets for inductors in the 100uH range that would be suitable for the buck converter indicate a tolerance of ±10%. This means that the values of 100uH that were calculated, and the value of 110uH that was found to give the response required from the circuit could overlap in terms of values and could be substituted. The capacitors, apart from the 15uF, 10uF and 21uF calculated, and the 813uF from the fourth source would all be suitable for the Buck converter. Capacitors with capacitance around this size have a tolerance of ±20%. The 110uH inductor and 45uF capacitor give the required ripple voltage and current for the circuit. For any inductor or capacitor used ideally a derating factor would be applied to choose the required values. An inductor with 150% current rating and capacitor 160% voltage rating of those calculated would be sufficient¹.

Conclusion

From the various sources examined to determine the size of the two main components, the inductor and output capacitor, five were found to give satisfactory results. These showed acceptable voltage ripple and inductor current ripple for a given set of circuit

parameters. The other four sources either had too much load voltage ripple or inductor current ripple. This is considering that the inductor has a tolerance of $\pm 10\%$, and capacitors $\pm 20\%$. These calculations show that design equation can be used to determine the correct size of inductor and capacitor for a Buck converter, but they may not always be correct. A simulation of the Buck converter with the calculated values will show if the design specifications are met from the set of design equations in question.

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