Design and Implementation of the DC-DC Buck Converter for High Power Application

S. Vignesh[1] A. Jainulafdeen[2] S. Aswin[3]
[1,2,3]Lecturer
[1,2,3]Department of Electrical & Electronics Engineering
[1,2,3]Sri Ramakrishna Mission Vidyalaya Polytechnic College, Coimbatore, India

Abstract— The dc-dc converters are some of the most widely used power electronics circuits for its high conversion efficiency and flexible output voltage. This converters used for electronic devices are designed to regulate the output voltage against the changes of the input voltage. This leads to the requirement of more advanced control methods to meet the real time demand. In this paper the buck converter is designed by choosing suitable values of capacitor, inductor and resistance for the given input and output.

Key words: DC-DC Buck Converter, High Power Application

I. INTRODUCTION

The switched mode dc-dc converters are some of the simplest power electronic circuits which convert one level of electrical voltage into another level by switching achievement. These converters have received an increasing deal of interest in several areas. This is due to their wide applications like power supplies for appliance control, personal computers, telecommunication equipment's, office equipment, DC motor drives, aircraft, automotive, etc. The analysis, control and equilibrium of switching converters are the leading factors that need to be considered. Several control methods are used for control of switch mode dc-dc converters and the simple and low cost controller structure is always in demand for most industrial and high performance applications. Each control method has some advantages and drawbacks due to which that particular control method consider as a proper control method under specific conditions compared to other control methods. The control method that gives the superlative performances under any conditions is always in demand.

II. THE DC-DC BUCK CONVERTER

The buck converter circuit converts a higher dc input voltage to lower dc output voltage. The basic buck dc-dc converter topology is shown in figure..1. It consists of a controlled switch S_w, an uncontrolled switch D (diode), an inductor L, a capacitor C, and a load resistance R.

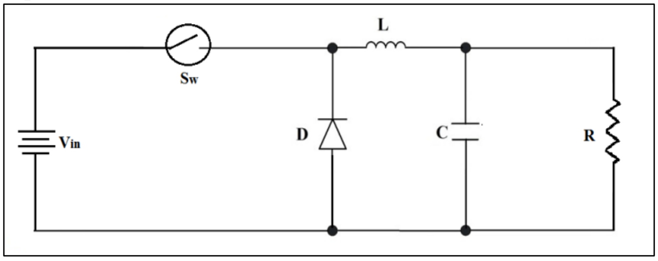

Fig. 1: Dc-dc buck converter topology

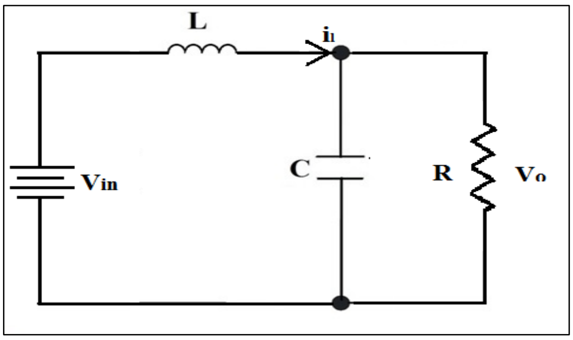

Fig. 2: Buck converter circuit when switch turns on

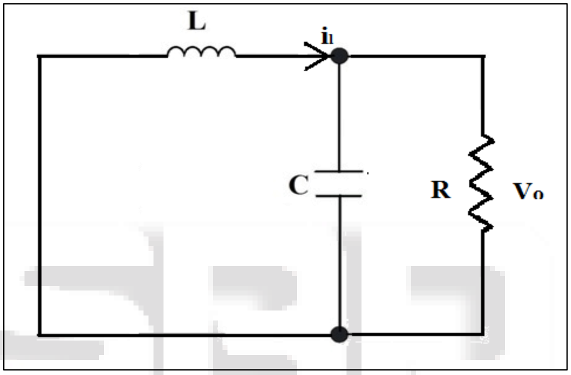

Fig. 3: Buck converter circuit when switch turns off

In the depiction of converter operation it is assumed that all the components are ideal and also the converter operates in continuous conduction mode (CCM). In this mode of operation, the inductor current flows continuously over one switching period. The switch is either off or on according to the switching function and this results in two circuit states. The first sub-circuit state stands when the switch is turned on and diode is reversed biased and inductor current flows through the switch, which can be shown in figure 2. The second sub-circuit state is when the switch is turned off and current freewheels through the diode which is shown figure 3.

III. DESIGNING OF BUCK CONVERTER

A. Duty Cycle

A duty cycle is the percentage of one period in which a signal is active. A period is the time its takes for a signal to complete an on and off cycle. As a formula duty cycle may be expressed as:

$$D = \frac{T}{P} \times 100\%$$

Where D is the duty cycle, T is the time the signal is active, and P is the total period of the signal. Thus, a 60% duty cycle means the signal is on 60% of the time but off 40% of the time. The "on time" for a 60% duty cycle could be a fraction of a second or a day depending on the length of the period.

B. Inductor

Output inductor in the Buck converter in addition to being a part of the low-pass filter for removing switching ripples from the output voltage, has two essential tasks:

1) "Limiting the current slew rate through power switches" which yields limiting in the peak current. This action reduces power loss in the circuit [6].

Whatever the inductor size is larger the peak inductor current and its ripple will be reduced, which yields enhancement in the converter's efficiency. But always there is a trade-off between the size of inductor and efficiency of DC/DC converter. On the other hand we have limitation for minimizing inductor size otherwise converter cannot work properly, for example the inductor current ripple will be increased which causes increase in power losses in the inductor and the power MOSFETs, therefore we can consider a boundary to select proper inductor size for having a higher efficiency and lower occupied area in the circuit.

2) The main advantage of employing inductor in switching mode power supply is "Storing energy" [6].

C. Capacitor

Capacitor is employed at the output stage of buck converter to minimize the voltage ripple and overshoot appear across the load. The capacitor should be large enough to prevent noticeable change in its voltage during discharging interval, so there is a limitation for minimizing the size of capacitor otherwise huge voltage ripple and overshoot will appear at the output stage. Large overshoots are caused by insufficient output capacitance, and large voltage ripple is affected by insufficient capacitance as well as a high equivalent series resistance (ESR) in the output capacitor.

The maximum allowed output voltage overshoot and ripple are usually part of buck converter's design specifications. Therefore, to meet the ripple specification for a buck converter circuit, the output capacitor should be selected with a sufficient capacitance and low ESR. On the other hand choosing an output capacitor with very low ESR may cause instability in the buck converter's system. In chapter 4 it will be discussed in more details that how ESR value can affect the stability of the converter's system.

D. Buck Switching Converter Design Equations

The buck converter is a high efficiency step-down DC-DC switching converter. The buck converter uses a transistor switch, MOSFET, to pulse width modulate the voltage to an inductor. Rectangular pulses of voltage to an inductor result in a triangular current waveform. We will derive the various equations for the current and voltage for a buck converter and display the trade-offs between ripple current and inductance. For this conversation we assume that the converter is in the continuous mode the inductor current never goes to zero.

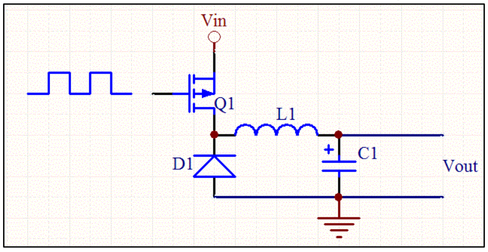

Fig. 4: DC-DC buck converter

First, here are some definitions:

Peak inductor current	i_{pk}
Min inductor current	i_o
Ripple Current	$\Delta i \equiv (i_{pk} - i_o)$
Ratio of Ripple Current to Average Current	$r \equiv \Delta i / i_{ave}$
Duty Cycle	$D \equiv T_{on}/T$
Switch On Time	$T_{on} = D/f$
Average and Load Current	$i_{ave} \equiv \Delta i/2 \equiv i_{load}$
RMS Current for a Triangular Wave	$i_{rms} = \sqrt{i_o^2 + (\Delta i)^2/12}$

Relationship between voltage and current for an inductor is:

$$V = L\frac{di}{dt} \text{ ,or}$$

$$i = \frac{1}{L}\int_o^t V dt + i_o$$

For a constant rectangular pulse:

$$i = \frac{Vt}{L} + i_o$$

From this we can see that the current is a linear ramp when the voltage is a constant pulse.

The transistor switch on the current is:

$$i_{pk} = \frac{(V_{in} - V_{Trans} - V_{out})T_{on}}{L} + i_o \text{ , or}$$

$$\Delta i = \frac{(V_{in} - V_{Trans} - V_{out})T_{on}}{L}$$

and the transistor switch off the current is:

$$i_o = i_{pk} - \frac{(V_{out} - V_D)T_{off}}{L} \text{ , or}$$

$$\Delta i = \frac{(V_{out} - V_D)T_{off}}{L}$$

Where V_D is voltage drop across the diode and V_{Trans} is voltage drop across the transistor. The continuous/discontinuous boundary occurs when i_o is zero.

By equating through delta i, we can solve for Vout:

$$\frac{(V_{in} - V_{Trans} - V_{out})T_{on}}{L} = \frac{(V_{out} - V_D)T_{off}}{L}$$

$$V_{in}T_{on} - V_{Trans}T_{on} - V_{out}T_{on} = V_{out}T_{off} - V_D T_{off}$$

$$V_{in}T_{on} - V_{Trans}T_{on} - V_{out}T_{on} = V_{out}T_{off} - V_D T_{off}$$

$$V_{out}T_{on} + V_{out}T_{off} = V_D T_{off} + V_{in}T_{on} - V_{Trans}T_{on}$$

$$V_{out} = \frac{V_D T_{off} + V_{in}T_{on} - V_{Trans}T_{on}}{T}$$

We can also solve for the duty cycle as follows,

$$V_{out} + V_D = (V_{in} - V_{Trans} + V_D)D$$

$$D = \frac{V_{out} - V_D}{(V_{in} - V_{Trans} - V_D)}$$

If neglect the voltage drops across the transistor and diode then:

$$V_{out} = DV_{in}$$

It's clear that the output voltage is related directly to the duty cycle of the pulses.

The main question when we designing a converter are what sort of inductor should be used. In maximum designs the input voltage, output voltage and load current are all dictated by the requirements of the design, but, the Inductance and ripple current are the only free parameters. It can be gotten form Equation 1, the inductance is inversely proportional to the ripple current. If you want to reduce the ripple, then use a larger inductor. Thus in exercise a ripple current is decided upon which will give a reasonable inductance.

There are adjustments with low and high ripple current. Large ripple current incomes that the peak current is i_{pk} greater and the greater probability of saturation of the inductor, and more pressure on the transistor.

Choosing an inductor make sure that the capacity current of the inductor is greater than i_{pk}. The transistor should be able to handle peak current greater than i_{pk}. The inductor should also be chosen such that can handle the suitable rms current.

IV. SIMULATION AND RESULTS

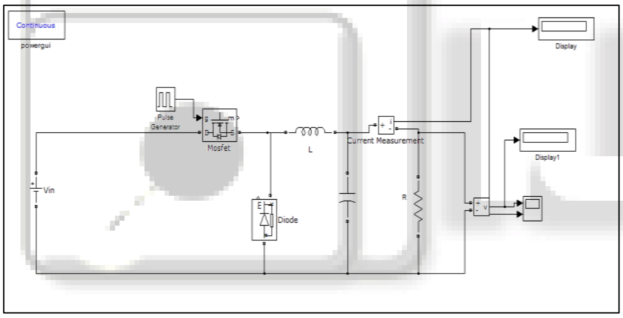

Fig. 5: Simulation diagram for open loop dc-dc buck converter

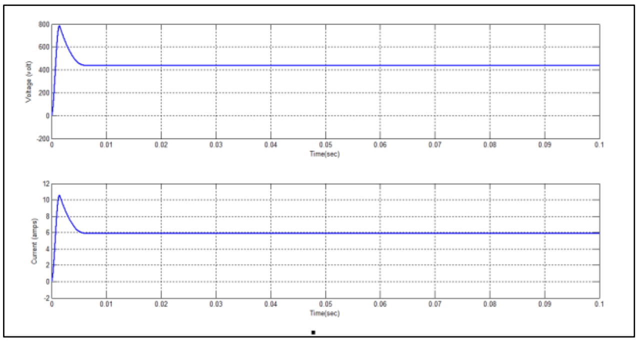

Fig. 6: Open loop voltage and current wave form

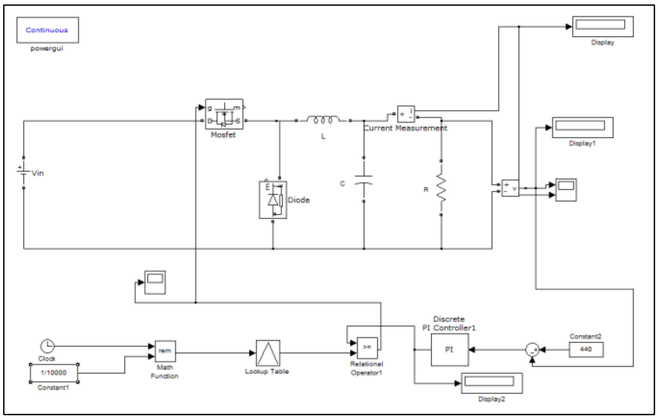

Fig. 7: Simulation diagram for closed loop dc-dc buck converter

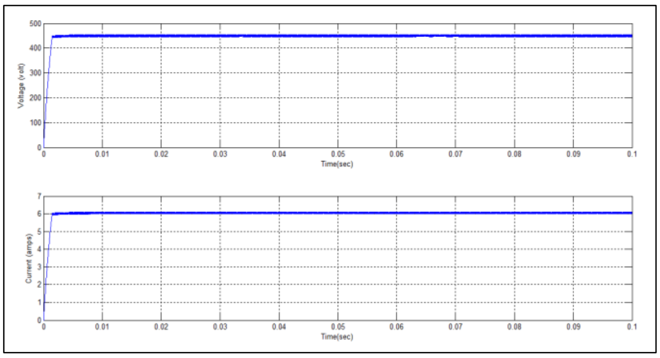

Fig. 8: Closed loop voltage and current wave form

V. CONCLUSION

Thus the dc- dc buck converter was designed by selecting suitable values of resistance, inductance and capacitance making it suitable for high power applications. The crucial part of the designing buck converter circuit is compensation network. In this thesis after a deep study about different types of compensation networks, due to low value of inductor ESR the compensation type III is employed and its elements value were calculated accurately to assurance the stability of the system and reduce the ripples at the output voltage, Also effect of changes in different factors and elements like load current, switching frequency and duty cycle on power efficiency, current and voltage ripple has been observed.

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