COMPARATIVE STUDY OF SELF-LIFT DC-DC CONVERTERS WITH HIGH VOLTAGE GAIN

Ajith Ashokan, Dr. Babu Paul, Jeena Joy
PG Student, Assistant Professor, Assistant Professor, Mar Athanasius College of Engineering, Kothamangalam, Kerala
ajithashokan135@gmail.com, 8129246511

Abstract—This paper discussed about two DC-DC converters with same design and different voltage gain. The voltage conversion ratio is different. Compared with the classical Cuk and buck–boost converters, the converter increases the voltage boost ability significantly using the switched capacitor and self-lift techniques. Here we discussed enhanced self-lift Cuk converter and self-lift Luo converter. It is featured with single power switch operation, common ground, transformerless structure, and clear energy delivery process. This compare study is done by MATLAB 2013a.

Keywords—Boost ability, DC–DC converter, Voltage gain, Cuk converter, Luo converter.

INTRODUCTION

Many applications of switch-mode DC-DC converters require higher conversion rates. An alternative solution to this problem is to use n-stages connected in cascade. Such that the total conversion rate can be increased by an order of n. However, the resulting problems, energy losses, multiple power switches, and large switching surges in transformers significantly increase the control complexity and the cost of these converters [1]. The use of the voltage multiplier technique applied to the classical non-isolated DC–DC converters in order to obtain high step-up static gain, reduction of the maximum switch voltage, zero current switching turn-on. The diodes reverse recovery current problem is minimized and the voltage multiplier also operates as a regenerative clamping circuit, reducing the problems with layout and the EMI generation. These characteristics allows the operation with high static again and high efficiency, making possible to design a compact circuit for applications where the isolation is not required. The operation principle, the design procedure and practical results obtained from the implemented prototypes are presented for the single-phase and multiphase DC–DC converters [2]. The derived circuits can increase the voltage-conversion ratios under the single power switch condition, but the number of passive components is also obviously increased. Classical nonisolated DC–DC topologies, such as switched-capacitor (SC), switched-inductor (SL), hybrid SC/SL, and voltage-lift (VL) techniques, have been greatly explored. The main advantage of SC techniques is the absence of inductors, thus making it very small in size and high in power density[3][4]. Switched-capacitor technology is widely used in low power DC–DC converter. This method can reduce the high pulse current which usually causes serious problem in traditional converters. The well-known one is the charge pump circuits. They are widely used in low power DC–DC converter, especially in power management of the integrated circuits. Usually, they use high-frequency switching actions and only use capacitors to transfer the energy [5]-[8].

In this paper, the concept of the voltage self-lift techniques has been integrated into an SC cell, and consequently, a new step-up circuit is proposed on the basis of the classical converter.

SELF-LIFT CUK CONVERTER

Introduction

The concept of the voltage self-lift techniques has been integrated into an SC cell, and consequently, a new step up circuit is on the basis of the classical Cuk converter. As shown in Fig 1. Compared with the conventional Cuk prototype, two additional components (diode D₁ and capacitor C₁) are added into the circuit. However, the relative positions of the other components are kept invariant in the new circuit. Different from the Cuk prototype, a 𝜋-type low-pass filter C₁-L₁-C₀ is constructed, and it results in the different voltage conversion mechanism. The voltage gain will be increase from D/(1-D) to (1)/(1-D). The voltage conversion is negative to positive polarity [9].
Self-lift cuk converter.

For the convenience of analysis, the whole circuit is divided into three different sections, as described in Fig. 1. L₁ belongs to the source section, and it performs the function of storing and transferring the energy from the source voltage \( V_{in} \) to \( C_s \) under the switching operation of S. C₁, D₁, and D₂ form a pump section, in which C₁ is charged by \( V_{cs} \) during each cycle and absorbs the energy stored in \( C_s \) like a pump. An output section formed by L₁ and \( C_o \) is combined with the pump section to perform the output filter function for the voltage of C₁.

**Working Principle**

The converter structure operates in Continuous Conduction Mode (CCM). This circuit contains two modes of operation: a) ON Period, b) OFF Period.

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**Mode 1 (During Switch ON):** The equivalent circuit during switching ON is shown in Fig 2(a). When switch S turns ON, D₁ is ON, and D₂ is OFF. C₁ performs characteristics to lift the output capacitor voltage \( V_{co} \) by the capacitor voltage \( V_{cs} \).

**Mode 2 (During Switching OFF):** The equivalent circuit during switching OFF is shown in Fig 2(b). When S turns OFF, D₁ is OFF, and D₂ is ON. C₁ performs characteristics to lift the output capacitor voltage \( V_{co} \) by the capacitor voltage \( V_{cs} \).

**Self-Lift Luo Converter**

**Introduction**

Voltage-lift technique is a popular method used in electronic circuit design. Applying this technique can effectively overcome the effect of the parasitic elements, and largely increase the voltage transfer gain.
Compared with above converter, number of the elements is equal and same design. The arrangements of the circuits are different. In this arrangement the voltage gain will be increase from $D/(1-D)$ to $(2-D)/(1-D)$. The voltage conversion is positive to positive polarity [10]-[12].

**Working Principle**

The converter structure operates in Continuous Conduction Mode (CCM). This circuit contains two mode of operation: a) OFF Period, b) ON Period

**Equivalent circuits.** (a) Switching OFF. (b) Switching ON.

*Modes 1 (During Switching OFF):* The equivalent circuit during switching OFF is shown in Fig 4(a) When S turns OFF, D₁ is OFF, and D₂ is ON. The capacitors C₁ and Cₛ are charging by source. C₁ and Cₛ perform characteristics to lift the output capacitor voltage $V_{co}$.

*Modes 2 (During Switching ON):* The equivalent circuit during switching ON is shown in Fig 4(b) When switch S turns ON, D₁ is ON, and D₂ is OFF. The capacitors C₁ and Cₛ are discharging through load. C₁ and Cₛ perform characteristics to lift the output capacitor voltage $V_{co}$.

**Design Of Components**

**Design of Inductor L**

Take input voltage $V_{in} = 12 \text{ V}$ and output voltage $V_o = 32 \text{ V}$, so the duty ratio $D = 0.63$ refers in equation Switching frequency $f = 50 \text{ kHz}$ and $\Delta i L = 0.3 \text{ A}$. The peak to peak current variation of $iL$, $\Delta i L = \frac{DV_{in}}{f}$

$$\therefore L = \frac{DV_{in}}{\Delta i L}$$  \hspace{1cm} (1)

**Design of Capacitor $C_s$**

The peak to peak current variation of $V_{cs}$, $\Delta V_{cs} = \frac{V_o}{R f C_s}$, Ripple voltage $\Delta V_{cs} = 0.06 \text{ mV}$ and load resistance $R = 100 \Omega$.

$$\therefore C_s = \frac{V_o}{R f \Delta V_{cs}}$$  \hspace{1cm} (2)

**Design of Capacitor $C_1$**

The peak to peak current variation of $V_{c1}$, $\Delta V_{c1} = \frac{V_o(1-D)}{R f C_1}$, Ripple voltage $\Delta V_{c1} = 0.1 \text{ mV}$ and load resistance $R = 100 \Omega$.

$$\therefore C_1 = \frac{V_o(1-D)}{R f \Delta V_{c1}}$$  \hspace{1cm} (3)

**Design of Inductor $L_1$**

The peak-to-peak current variation of $iL_1$ can be calculated by the area A of a triangle with width $T/2$ and the height $V_{c1}/2$,

$$L_1 = \frac{V_o(1-D)}{8R C_1 f^2 \Delta V_{c1}}$$  \hspace{1cm} (4)
Design of Capacitor $C_o$

The peak-to-peak voltage variation of $V_o$ is calculated by the area $B$ of a triangle with width $T/2$ and the height $\Delta iL_1/2$

$$C_o = \frac{V_o(1-D)}{64RF^2L_1C_1\Delta V_{co}}$$  \quad (5)

SIMULATION MODEL AND RESULTS

Self-Lift Cuk Converter Model

The simulation of the Cuk converter is done with the help of MATLAB SIMULINK. Here, discussed about two type of model, one is open model and other one is closed loop. In closed loop, PI controller is used for feedback signal.

Self-lift Cuk converter model. (a) Open. (b) Closed.
The main circuit parameters are chosen as follows: For an input voltage is 12V with load = 100Ω, L = 500µH, C = 110µF, C1 = 22µF, L1 = 500µH, C0 = 47µF and f = 50 kHz. All the components are assumed ideal, and the voltage conversion aim is set as +32 V, as shown in Fig. 5(a). In order to increase the performance of the system closed path is provided. PI controller is used for controller purpose. The closed loop configuration of converter using PI controller, with Kp=0.01 and Ki=0.75 Pulse is created with the help of relational operator. Direct output of relational operator is given to gate signal.

**Self-Lift Luo Converter Model**

The simulation of the Luo converter is done with the help of MATLAB SIMULINK. Here, discussed about two type of model, one is open model and other one is closed loop. In closed loop, PI controller is used for feedback signal.

![Self-Lift Luo Converter Model](a)

![Self-Lift Luo Converter Model](b)

Self-lift Luo converter model. (a) Open. (b) Closed.

The models of self-lift Luo converter in open and closed model are shown in Fig. 6(a) and (b), respectively.

**Self-Lift Cuk Converter Results**

The input voltage of the converter is 12 V. Input voltage wave form is shown in Fig 7(a). Output voltage of the Cuk converter in open model is 32.69 V is shown in Fig 7(b). The output voltage of the Cuk converter in closed model is 32V and reference voltage is 32 V is shown in Fig 7(c). Input current of the converter is 1.92 A is shown in Fig 7(d). Output current of the converter is 3.269 A, current waveform is shown in Fig 7(e). Duty ratio is 63% as shown in Fig. 7(f).
Simulated results in self-lift Cuk converter (a) Input Voltage (b) Output Voltage in open (c) Output Voltage in Closed (d) Input Current (e) Output Current, (f) Switching pulse

Self-Lift Luo Converter Results

The input voltage of the converter is 12 V. Output voltage of the Cuk converter in open model is 42 V is shown in Fig 8(a). Output current of the converter is 0.42 A, current waveform is shown in Fig 8(b). Input current of the converter is 3.4 A is shown in Fig 8(c). Duty ratio is 63% as shown in Fig. 8(f).
CONCLUSION

By an in-depth topology analysis, it is known that the circuit (i.e., enhanced self-lift Cuk converter) can increase the voltage boost ability of the classical Cuk converter to a higher level. A negative to positive conversion path is provided to make it suitable for negative DC-voltage source with respect to the common ground. It also has the characteristics of high efficiency smooth currents at both sides, and small ripples in simple structures. It might be developed and used in the areas of various DC distributed power systems. Here input voltage is -12 V, and output is 32V.

In Luo converter voltage boosting capability is increase, with equal number of elements and same design. A positive to positive conversion path is provided. Here input voltage 12V and output is 42 V. These works is done by MATLAB SIMULINK 2013a.

REFERENCES: