Design and Analysis of High Gain DC-DC Converter for Single-Phase Grid-Tied Systems

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Abstract: In general, conventional DC-DC converters are preferred due to their simple structure. However, they may also cause various problems such as a limited voltage transfer gain due to the effect of parasitic components and power switches. It must be also noted that in conventional converters, an increasing intended output voltage significantly contributes to a higher duty ratio, thus causing a higher number of switching losses for them. Luo converters with a very high step-up ability thanks to the voltage lift and super lift method can be used to cope with the setbacks of conventional converters. The super-lift Luo converter utilizes super-lift method that allows a high output voltage gain in geometric progression for high power applications. It also reduces current and voltage ripples and offers a low switching element loss, high output voltage and high power conversion efficiency compared to other conventional DC-DC converters. The present study focuses on the design and analysis of transformer-less high voltage gain super-lift Luo converter for single phase grid tied systems. The output voltage durability of positive output elementary super-lift Luo converter was used as a performance criterion.
Keywords: High Voltage Gain, Transformer-less DC-DC converter.

1. Introduction

The super lift Luo series converters possess a super lift method that allows the output voltage to increase geometrically, which increases voltage gain considerably (Luo and Ye 2016). They have been a popular tool for many researchers to connect load or grid (Kececioglu, 2022), and are commonly used for DC voltage or current regulation in accordance with single-phase or three-phase grid-tied input requirements (Hossain and Rahim 2018). The main advantage of the proposed high gain converter topology is high power transfer efficiency for single phase grid-tied systems. The proposed high voltage gain of converter enables an operation without transformer (Kececioglu, 2019). With respect to the latest literature review, a few studies were carried out to design and analyze super lift Luo series converters (Tekade et al. 2016, Kaliannan et al. 2021, Glady and Manjunath 2017, Adlakha et al. 2020, Sener et al. 2018). In the present study, the design and analysis of positive output elementary Luo series super lift converter was performed for single-phase grid-tied systems. To this aim, a 24W positive output elementary Luo series super lift converter was analyzed in detail in Matlab/Simulink. The rest of the present study is structured as follows: In Section 2, material and method are described. Section 3 presents simulation studies. Finally, the conclusions are outlined in Section 4.

2. Material and Method

Introduced by Luo and He (Luo and Ye 2003), the super lift Luo series converter topologies offer a higher voltage gain compared to classical converters, resulting in a lower number of switching losses and a higher efficiency (Abjadi et al. 2018).The main series of this converter topology possesses three configurations, namely elementary, re-lift, and triple-lift circuit with respect to the value of voltage gain. The elementary circuit configuration used in the present study is shown in Figure 1 (a). While in steady-

state, elementary circuit configuration is analyzed in two modes: switch (on) and switch (off). The equivalent circuit configurations during switch (on) and switch (off) are shown in Figure 1 (b) and (c), respectively. These modes were used to define mathematical equations of elementary circuit configuration.

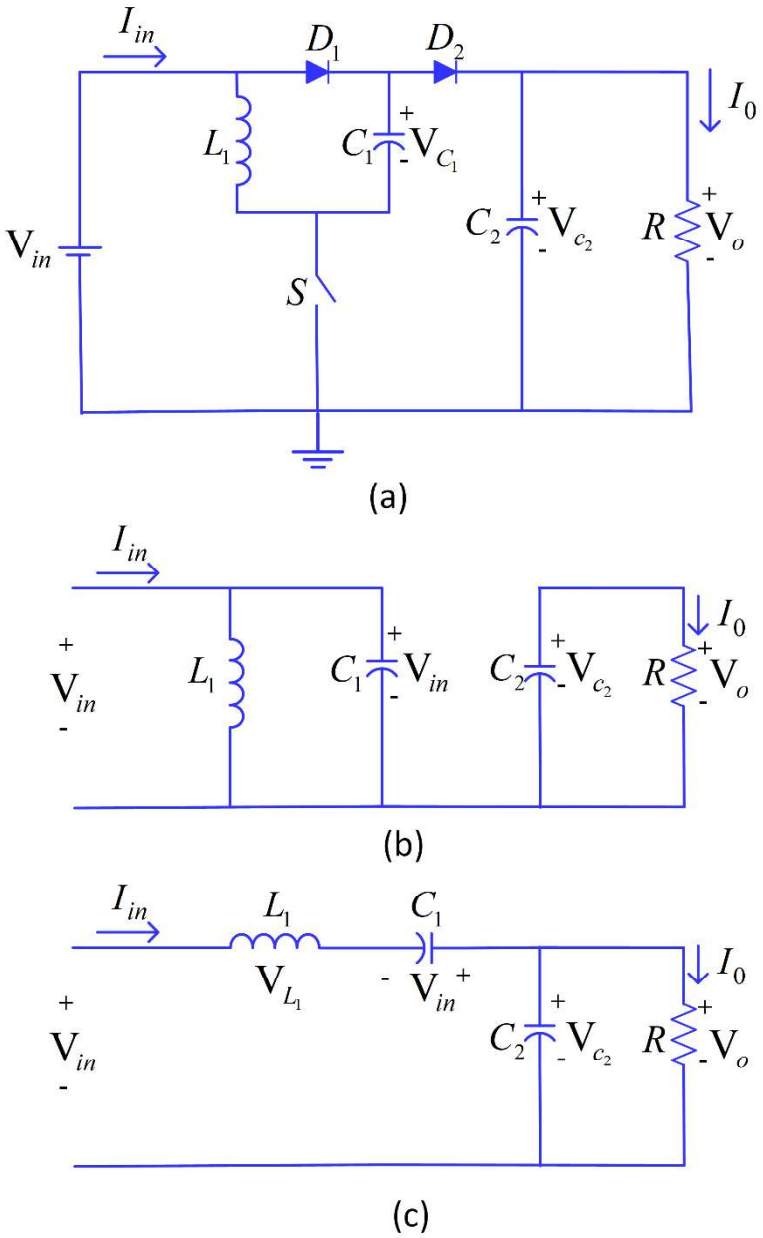


Figure 1. The elementary circuit configuration of super lift Luo converter (a) Equivalent circuits for switch on (b) and switch off (c)

When the S switch is (on), input voltage (V_{in}) charges the inductor L_1 and capacitor C_1, and $V_{C1} = V_{in}$ at steady state. On the other hand, when the S switch is (off), inductor L_1 and capacitor C_1 lifts the output voltage (V_O) from input voltage highly, which is expressed in the following equation (Luo and Ye, 2017):

$$V_0 = \frac{2-k}{1-k} V_{in} \quad (1)$$

Here, k is the duty cycle. The voltage gain (*G*) of elementary super lift Luo converter is expressed as follows:

$$G = \frac{V_0}{V_{in}} = \frac{2-k}{1-k} \quad (2)$$

The relation between duty cycle (k) and voltage gain (G) of elementary super lift Luo converter is illustrated in Figure 2.

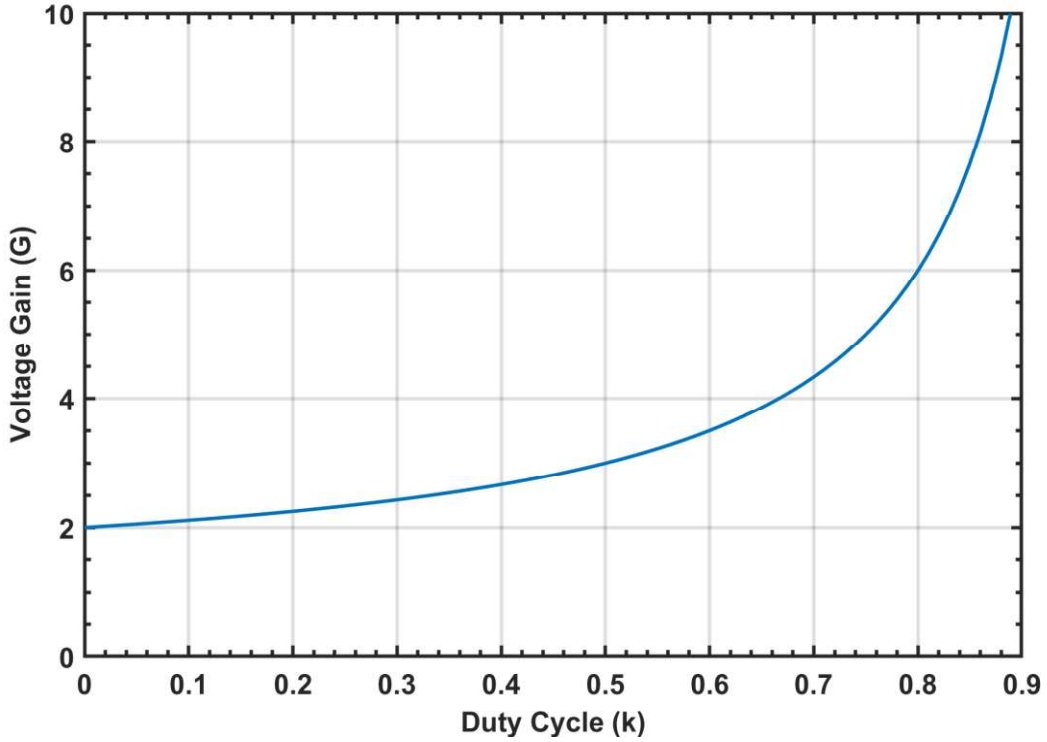


Figure 2. The relation between duty cycle and voltage gain of elementary super lift Luo converter

Figure 2 clearly demonstrates that a very low variation in duty cycle leads to a large change in output voltage.

2.1. Design Constraints of elementary super lift Luo converter

In elementary super lift Luo converter analysis, element boundary values are calculated using Equation (3-4) based on current changes in inductors and voltage changes in capacitors. The variation ratio of the current through L_1 inductor is calculated as:

$$\xi_1 = \frac{\Delta I_{L_1} / 2}{I_{L_1}} = \frac{k(1-k)^2}{2(2-k)} \frac{R}{fL_1} \tag{3}$$

Generally, ξ_1 is a very small value, which means that this converter normally operates at continuous conduction mode. The variation ratio of voltage across C_2 capacitor can be given as:

$$\varepsilon = \frac{\Delta V_O / 2}{V_O} = \frac{k}{2RfC_2} \tag{4}$$

Similarly, the variation ratio of voltage across C_1 capacitor is calculated using Equation 4. The calculated boundary element values of elementary super lift Luo converter are given in Table 1.

Table 1. The calculated boundary element values of elementary super lift Luo converter

Parameter	Symbol	Value
Inductance	L_1	0.25 mH
Capacitance	C_1	2.5μF
Capacitance	C_2	2.5μF
Load Resistance	R	150Ω
Switching Frequency	f	50kHz
Duty Cycle	k	0.77
Variation ratio of voltage across capacitance	ε	0.02
Variation ratio of current through inductance	ξ_1	0.2

Real converter values should be selected higher than boundary values for continuous conduction mode. The selected elementary super lift Luo converter parameters for simulation studies are given in Table 2.

Table 2. The selected element values of elementary super lift Luo converter

Parameter	Symbol	Value
Inductance	L_1	10 mH
Capacitance	C_1	47μF
Capacitance	C_2	22μF
Input Voltage	V_{in}	60V
Output Voltage	V_o	320V

3. Simulation Studies

In this section, elementary super lift Luo converter are modeled using MATLAB/Simulink. To validate the design of elementary super lift Luo converter, its open loop response is analyzed based on constant duty cycle. For inverters used in single-phase grid-tied system to perform DC/AC conversion, the minimum peak value of the output voltage must be at least 311V for the converter. In this respect, the output voltage is adjusted to 320V. The open loop response of the converter for single-phase grid-tied system is shown in Figure 3.

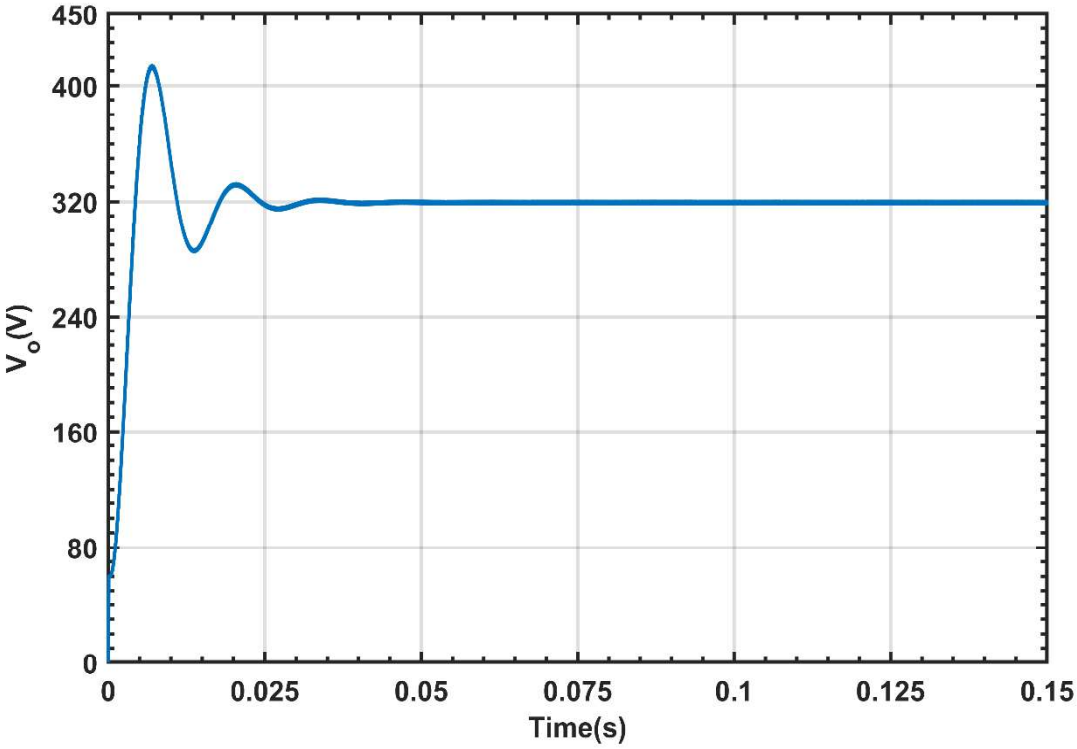


Figure 3. The open loop response of elementary super lift Luo converter for single-phase grid-tied system

As shown in Figure 3, total simulation time was 0.15 s. According to the obtained results, transient response parameters of elementary super lift Luo converter are calculated as 0.04 s., 0.004 s. and 28.44% for settling time, rise time and overshoot, respectively.

4. Conclusions

The findings of the simulation study via Matlab/Simulink demonstrated that positive output of the elementary super-lift Luo converter topology was effective and durable for single phase grid-tied systems in terms of different performance requirements such as settling time, rise time and overshoot. Therefore, it can be stated that the positive output elementary super-lift Luo converter is feasible for a very high output voltage such as grid-tied systems.

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