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Analysis of a Positive Output Super-Lift Luo Boost Converter

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ABSTRACT
This paper presents a DC-DC conversion technique using Positive Output Super-lift Luo Boost Converter circuit. In recent trends, in various industries DC-DC conversion has gained greater importance for various applications. This DC-DC conversion can be conveniently obtained by Super-lift Luo Boost converter. By employing voltage lift technique, output voltage is increased stage by stage in arithmetic progression. But by using Super-lift technique, output voltage is increased in geometric progression. Super-lift Luo converters are generally useful for high output voltage applications over the years. These converters enhance the voltage transfer gain very effectively. An extensive simulation of Super-lift Luo Boost Converter is carried out on the basis of reference values in MATLAB/Simulink environment. In order to calculate the converter parameters MATLAB program has been used.
***Keywords* -** Arithmetic Progression, DC-DC Converter, Geometric Progression, Super-Lift, Voltage Gain

I. INTRODUCTION

In DC-DC Converter circuit design, voltage lift (VL) and super-lift (SL) technique are popular method widely used for boosting the voltage [1]. In recent years these techniques have been successfully employed in DC-DC converters and have opened various opportunities to design high voltage gain converters. However in voltage lift technique the output voltage increases stage by stage in arithmetic progression and that in super-lift technique the output voltage increases in geometric progression [2]. In power series, the voltage transfer gain is effectively enhanced due to this technique [3].

These converters are generally termed as; "positive output Super-Lift Luo Boost converters" in order to sort these converters different from existing voltage lift converters [4]. The series of these positive output super-lift converters can be divided into main series and additional series. Each main series circuit contains one switch '*S*', '*n*' inductors, (3*n*-1) diodes and '2*n*' capacitors. The conduction duty ratio is '*k*', switching frequency is '*f*' (period *T*=1/*f*), the load is resistive output current is I_o. For increasing the stages only passive elements are increased where as the number switch is not changed and is kept only one[5]-[7]. Assuming no power loss during conversion process, $V_{in}*I_{in}=V_o*I_o$. The voltage transfer gain is G: $G = V_o/V_{in}$.

The section II describes the complete analysis of the Main series circuit like Elementary circuit, Re-lift Circuit and Triple- Lift circuit. Section III reflects the various stages of Positive Output Super-Lift Converter. It also covers voltage gain of various DC-DC converters. Section IV contains the mathematical calculation for various circuit parameters of Elementary circuit of a Positive Output Super-Lift Luo Converter using a MATLAB Program. Section V shows the simulated results of the Elementary circuit, Re-lift circuit and Triple-Lift circuit of Positive Output Super- Lift Luo Converter.

II. MAIN SERIES

Positive output super-lift converters are being shown for first three stages. For simplicity to explain, the Super- Lift Luo converter circuits are called as Elementary circuit, Re-lift circuit and Triple-lift circuit, respectively. These series may be numbered as *n*=1, 2, 3.

2.1 Elementary circuit of Positive Output SL Converter

The elementary circuit along with its equivalent circuits during switch-on and switch-off period is shown in Fig. 1. The voltage across capacitor C_1 is charged to V_{in} during switch-on period. The current flowing through inductor L_1 is i_{L1} and increases with input voltage V_{in} during switch-on period kT.

The inductor current i_{L1} decreases with voltage (V_o-2V_{in}) during switch-off period (1-*k*)*T*. Therefore the ripple of the inductor current i_{L1} ;

$$\Delta i_{L1} = \frac{V_{in} * k * T}{L_1} = \frac{V_o - 2V_{in}(1-k)T}{L_1} \quad \text{…. (1)}$$

$$V_o = \left(\frac{2-k}{1-k}\right)V_{in} \quad \text{…. (2)}$$

The voltage transfer gain:

$$G = \frac{V_o}{V_{in}} = \left(\frac{2-k}{1-k}\right) \quad \text{…. (3)}$$

The input current i_{in} is equal to $(i_{L1} + i_{C1})$

$$I_{in-on} = i_{L1-on} + i_{C1-on}$$

$$I_{in-off} = i_{L1-off} = i_{C1-off}$$

$$kTi_{C1-on} = (1-k)Ti_{C1-off}$$

If inductance L_1 is large enough then i_{L1} is nearly equal to its average current I_{L1} Therefore

$$i_{in-off} = i_{C1-off} = I_{L1},\ i_{in-on} = I_{L1} + \left(\frac{1-k}{k}\right)I_{L1} = \frac{I_{L1}}{k}$$

$$i_{C1-on} = \left(\frac{1-k}{k}\right)I_{L1}$$

and average input current :

$$I_{in} = ki_{in-on} + (1-k)i_{in-off} = I_{L1} + (1-k)i_{L1} = (2-k)I_{L1} \quad \text{…. (4)}$$

Considering T=1/f and

$$\frac{V_{in}}{I_{in}} = \left(\frac{1-k}{2-k}\right)^2 . \frac{V_o}{I_o} = \left(\frac{1-k}{2-k}\right)^2 R$$

The variation ratio of inductor current i_{L1} :

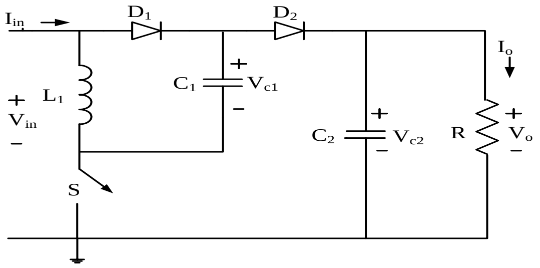
$$\xi = \frac{\Delta i_{L1}/2}{I_{L1}} = \frac{k(2-k)TV_{in}}{2L_1 I_{in}} = \frac{k(1-k)^2 R}{2(2-k)fL_1} \quad \text{…. (5)}$$

The ripple voltage of output V_o :

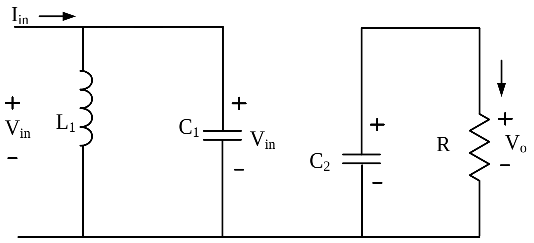
$$\Delta v_o = \frac{\Delta Q}{C_2} = \frac{I_o(1-k)T}{C_2} = \frac{(1-k)V_o}{fC_2 R}$$

Therefore, the variation ratio of output voltage V_o :

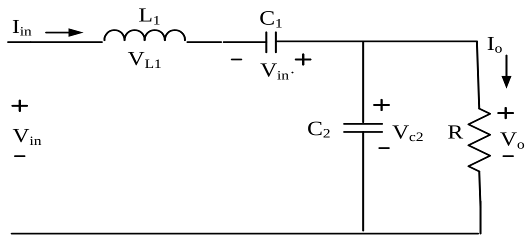
$$\varepsilon = \frac{V_o/2}{V_o} = \frac{1-k}{2RfC_2} \quad \text{…. (6)}$$



(a)



(b)



(c)

Fig.1. Elementary circuit of Positive Output Super-lift Luo Boost Converter :(a) Elementary Circuit diagram; (b) Equivalent Circuit diagram during switch-on period; (c) Equivalent Circuit diagram during Switch-off period.

2.2 Re-Lift Circuit of Positive Output SL Converter

The Re-lift circuit is obtained by adding (L_2-D_3-D_4-D_5-C_3-C_4) to the elementary circuit. Its circuit diagram along with its equivalent circuit during switch-on and switch-off is shown in Fig.2. The capacitor C_1 is charged to input voltage V_{in}. The voltage V_1 across capacitor C_2 is given by V_1= ((2-k)/(1-k))V_{in} as described in previous section.

The voltage across capacitor C_3 is charged to V_1. The current in inductor L_2 increases with voltage V_1 during the switch-on period kT and it decreases with voltage (V_o-2V_1) during switch-off period (1-k)T. The ripple in inductor current i_{L2} is

$$\Delta i_{L2} = \frac{V_1 kT}{L_2} = \frac{Vo - 2V_1(1-k)T}{L_2} \quad \text{…. (7)}$$

$$V_o = \left(\frac{2-k}{1-k}\right)V_1 = \left(\frac{2-k}{1-k}\right)^2 V_{in} \quad \text{…. (8)}$$

The voltage transfer gain is

$$G = \frac{V_o}{V_{in}} = \left(\frac{2-k}{1-k}\right)^2 \quad \text{…. (9)}$$

Hence, the expressions for ripples in inductor current and current through inductor are obtained as-

$$\Delta i_{L1} = \frac{V_{in}kT}{L_2} \qquad I_{L1} = \frac{I_{in}}{2-k}$$

$$\Delta i_{L2} = \frac{V_1 kT}{L_2} \qquad I_{L2} = \left(\frac{2-k}{1-k} - 1\right)I_o = \frac{I_o}{1-k}$$

So, the variation ratio of inductor current i_{L1} is

$$\xi_1 = \frac{\Delta i_{L1}/2}{I_{L1}} = \frac{k(2-k)TV_{in}}{2L_1 I_{in}} = \frac{k(1-k)^4 R}{2(2-k)^3 fL_1} \quad \text{…. (10)}$$

The variation ratio of inductor current i_{L2} :

$$\xi_2 = \frac{\Delta i_{L2}/2}{I_{L2}} = \frac{k(1-k)TV_1}{2L_2 I_o} = \frac{k(1-k)^2 TV_o}{2(2-k)L_2 I_o} = \frac{k(1-k)^2 R}{2(2-k)fL_2} \quad \text{…. (11)}$$

And variation ratio of output voltage V_o:

$$\varepsilon = \frac{\Delta v_o/2}{V_o} = \frac{1-k}{2RfC_4} \quad \text{.... (12)}$$

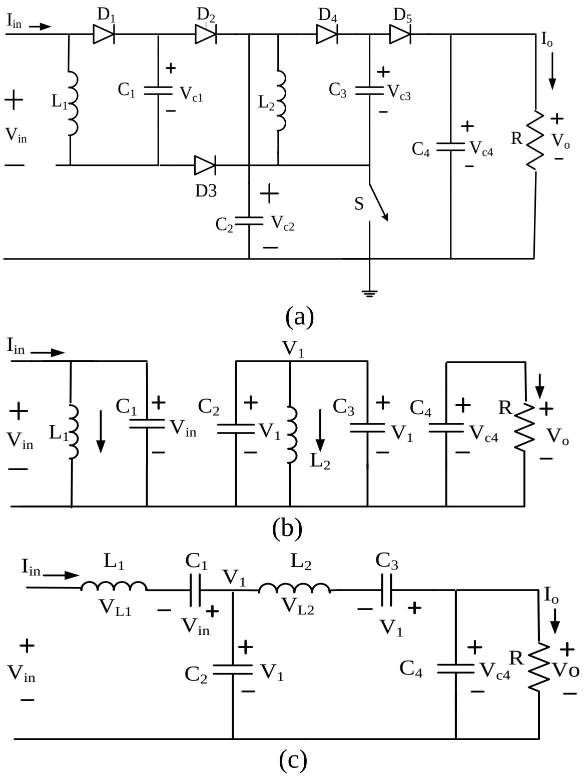


Fig.2. Re-Lift Circuit of Positive Output Super-lift Luo Boost Converter: (a) Re-lift circuit diagram; (b) Equivalent Circuit diagram during Switch-on; (c) Equivalent circuit diagram during Switch-off.

1.3 Triple-Lift Circuit of Positive Output SL Converter

The Triple-lift circuit is obtained by adding (L_3-D_6-D_7-D_8-C_5-C_6) to the Re-lift circuit. Its circuit diagram along with its equivalent circuit diagram during switch-on and switch-off are shown in Fig.3. The capacitor C_1 is charged to V_{in}, the voltage across capacitor C_2 is $V_1=((2\text{-}k)/(1\text{-}k))V_{in}$, and voltage across capacitor C_4 is $V_2=((2\text{-}k)/(1\text{-}k))^2V_{in}$.

During switch-on period kT, the current flowing through inductor L_3 increases with voltage V_2 and during switch-off period $(1\text{-}k)T$ it decreases with voltage (V_o-2V_2). Now the ripple of inductor current i_{L2} :

$$\Delta i_{L3}=\frac{V_2kT}{L_3}=\frac{V_o-2V_2}{L_3}(1-k)T \qquad \text{…. (13)}$$

$$V_o=\frac{2-k}{1-k}V_2=\left(\frac{2-k}{1-k}\right)^2V_1=\left(\frac{2-k}{1-k}\right)^3V_{in} \qquad \text{…. (14)}$$

The voltage transfer gain :

$$G=\frac{V_o}{V_{in}}=\left(\frac{2-k}{1-k}\right)^3 \qquad \text{…. (15)}$$

Hence, the expressions for ripples in inductor current and current through inductor are obtained as:

$$\Delta i_{L1}=\frac{V_{in}kT}{L_2} \qquad I_{L1}=\frac{I_{in}}{2-k}$$

$$\Delta i_{L2}=\frac{V_1kT}{L_2} \qquad I_{L2}=\frac{2-k}{(1-k)^2}I_o$$

$$\Delta i_{L3}=\frac{V_2kT}{L_3} \qquad I_{L3}=\frac{I_o}{1-k}$$

Now, the variation ratio of current i_{L1} through inductor *L1* :

$$\xi_1=\frac{\Delta i_{L1}/2}{I_{L1}}=\frac{k(2-k)TV_{in}}{2L_1I_{in}}=\frac{k(1-k)^6}{2(2-k)^5}\frac{R}{fL_1} \qquad \text{…. (16)}$$

The variation ratio of current i_{L2} through inductor L_2 is

$$\xi_2=\frac{\Delta i_{L2}/2}{I_{L2}}=\frac{k(1-k)^2TV_1}{2(2-k)L_2I_o}=\frac{kT(2-k)^4V_o}{2(1-k)^3L_2I_o}=\frac{k(2-k)^4}{2(1-k)^3}\frac{R}{fL_2} \qquad \text{…. (17)}$$

The variation ratio of current i_{L3} through inductor L_3 is

$$\xi_3=\frac{\Delta i_{L3}/2}{I_{L3}}=\frac{k(1-k)TV_2}{2L_3I_o}=\frac{k(1-k)^2TV_o}{2(2-k)L_2I_o}=\frac{k(1-k)^2R}{2(2-k)fL_3} \qquad \text{…. (18)}$$

The, variation ratio of output voltage V_o *:*

$$\varepsilon=\frac{\Delta v_o/2}{V_o}=\frac{1-k}{2RfC_6} \qquad \text{…. (19)}$$

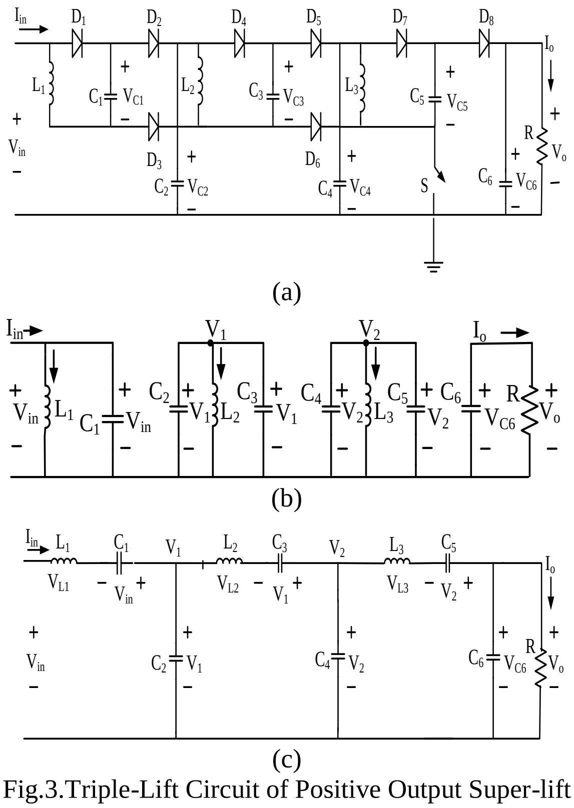


Fig.3.Triple-Lift Circuit of Positive Output Super-lift Luo Boost Converter: (a) Triple-Lift circuit diagram; (b) Equivalent circuit Diagram during Switch-on; (c) Equivalent circuit diagram during Switch-off.

III. SUMMARY OF POSITIVE OUTPUT SUPER-LIFT LUO BOOST CONVERTERS

Various stages of Positive Output Super-lift Luo Boost converters can be arranged in ascending pattern as shown in Fig.4.

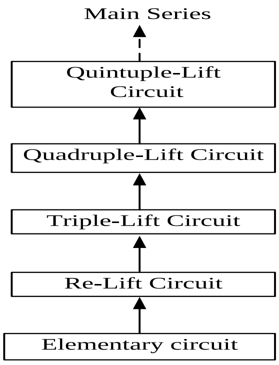


Fig.4. Various stages of Positive Output Super-lift Luo Boost converter.

From analysis of previous section II, for calculating the output voltage and voltage transfer gain of Super-Lift Converter the common formula given below-

$$V_o = \left(\frac{2-k}{1-k}\right)^n V_{in}$$

$$G = \left(\frac{V_o}{V_{in}}\right) = \left(\frac{2-k}{1-k}\right)^n$$

(n – number of stages)

In order to show the advantage of Super-Lift Luo Boost Converter, following comparison is made with respect to voltage transfer gains of various converters.

Buck Converter, $G = \frac{V_o}{V_{in}} = k$

Forward Converter, $G = \frac{V_o}{V_{in}} = kN$

(N is transformer turns ratio)

Cuk-Converter, $G = \frac{V_o}{V_{in}} = \frac{k}{1-k}$

Fly-back Converter, $G = \frac{V_o}{V_{in}} = \frac{k}{1-k}N$

(N is transformer turns ratio)

Boost Converter, $G = \frac{V_o}{v_{in}} = \frac{1}{1-k}$

Positive Output Luo Converter, $G = \frac{V_o}{V_{in}} = \frac{n}{1-k}$

IV. MATHEMATICAL RESULT

From the design point of view various circuit parameters are need to be calculated. Henceforth mathematical calculations for an Elementary Circuit of a Positive Output Super-Lift Luo Converter can be given by a MATLAB program as given below. Similarly, for the calculation of parameters for Re-Lift Circuit and Triple-Lift Circuit can be formed.

MATLAB Program for Elementary Circuit:-

```
clc
clear all
R=30e3;
f=100e3;% switching frequency
vo=60;%Output voltage
k=0.5;% duty ratio
di=0.01;% ripple in current
dv=0.005;% ripple in voltage
T=1/f
vin=vo*((1-k)/(2-k))%Input voltage
L1=(vin*k)/(di*f)
x=(k*(1-k)^2*R)/(2*(2-k)*f*L1)%variation in
inductor current ratio
iL1=(di/2)/x
Iin=(2-k)*iL1
C2=(k*vo)/(f*R*dv)
Io=(dv*C2)/((1-k)*T)
y=(dv/2)/vo%variation in output voltage ratio
pin=vin*Iin%input power
po=vo*Io% output power
```

Program Output :-

```
T =1.0000e-005
vin =20
L1 =  0.0100
x = 1.2500
iL1 =  0.0040
Iin =0.0060
C2 =2.0000e-006
Io = 0.0020
y =  4.1667e-005
pin =0.1200
po =  0.1200
```

Thus parameters for Super Lift converters are given in Table 1 given below:-

Table 1 Calculated Parameters using MATLAB Program.

Parameters	L_1	$C_1 = C_2$	P_{in}	P_{out}
Values	10mH	2μF	0.1200	0.1200

V. SIMULATION RESULT

To verify the design and calculation results, MATLAB software is used for Super-Lift Luo converter design. MATLAB Program parameters for Simulation are considered as V_{in}=20V, L_1=L_2=L_3=10mH, all the capacitors i.e. C_1-C_8=2μF and R=30kΩ for k=0.5 and f=100kHz.

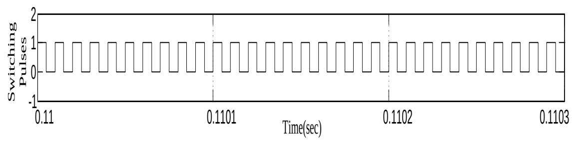


Fig.5. Waveform of Switching pulses.

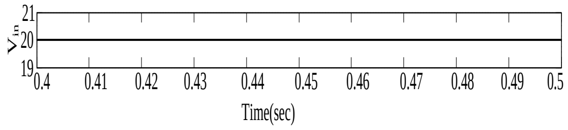


Fig.6. Waveform of Input Voltage to Positive Output Super-lift converter.

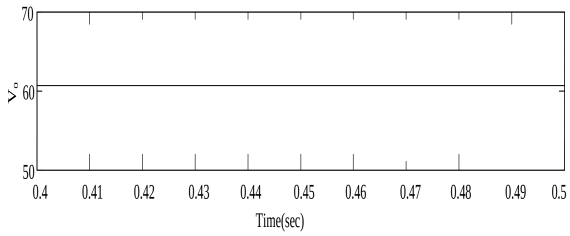


Fig.7. Waveform of Output Voltage for 1st stage that is for Elementary circuit of Positive Output Super-lift Converter.

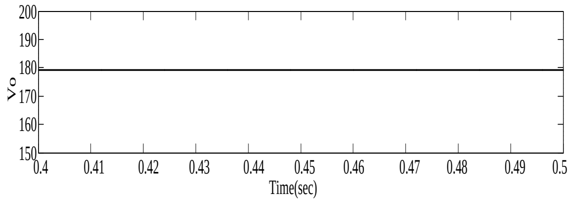


Fig.8. Waveform of Output Voltage for 2nd stage i.e. for Re-lift Circuit of Positive Output Super-lift Converter.

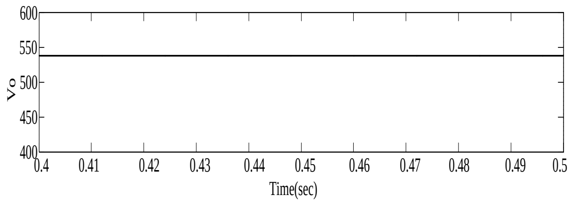


Fig.9. Waveform of Output Voltage for 3rd stage i.e. for Triple-Lift circuit of Positive Output Super-Lift Converter.

Table 2 Comparison to Theoretical and simulated Results of a Positive Output Super-Lift Luo Converter.

No. of Stages	1	2	3
Input voltage	20V	20V	20V
Theoretically calculated Output Voltage	60V	180V	540V
Simulated Output Voltage	59.78V	179.2V	537.6V

Thus the output voltages of Positive Output Super-Lift Converter for various stages are obtained. We have also observed that the output voltage increases with addition of every stage to elementary circuit. Fig.5 shows the waveform of switching pulse of MOSFET. Fig.6 shows the input voltage waveform for the Super-Lift Luo converter circuit. Fig.7 shows the output voltage waveform of the Elementary circuit of Positive Output Super-Lift Luo converter. Fig.8 shows the waveform of Output Voltage of Re-Lift Circuit of Positive Output Super-Lift Luo Converter. Fig.9 shows the output voltage waveform of the Triple-Lift circuit of Positive Output Super-Lift Luo converter.

Thus obtained simulated output voltage values V_o of an Elementary circuit, Re-lift circuit and Triple-lift circuit. The simulation results are shown in Table 2. The simulated voltage values are nearly equal to the theoretically calculated results.

VI. CONCLUSION

Positive Output Super lift Converter has been successfully analyzed and simulated. It largely increases output voltage and voltage transfer gain in power circuit. The simulation results and theoretical results verified the design and calculations. It has been observed that the output voltage has increased in geometric progression. The circuit parameters can be calculated by using the MATLAB program for various applications.

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