An Analysis Of Positive Output Cascade Boost Converter For Electric Vehicle Applications

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Abstract: This paper analyse the cascade boost DC-DC converter for battery charging applications and compared with the conventional boost DC-DC converter for achieving high step up voltage. The implementations of the output cascade boost DC-DC converters are designed and simulated under two modes, such as resistive load and battery charging Electric Vehicle (EV) system. This paper introduces the positive output cascade boost converter which gives high gain step-up voltage for high voltage power utilization. The conventionally available boost converters cannot be used for lower power applications and also limited to meet high current demand with reduced complexity and improved voltage gain. For high power applications, the positive output cascade boost converter is an ultimate choice owing to its improved performance parameters. The cascade boost converter can be used for high voltage applications such as, EV, Battery charging and Photo voltaic applications. A non linear control method is used to control the power devices of a cascade boost converter and the simulations were carried out in MATLAB Simulink.

1 INTRODUCTION

Dc- DC conversion become very significant in various portable applications at present. Many compact devices use power at different levels of voltage [1]. The positive output cascade boost converters (POCBC) will be an ultimate choice for the output voltage increase in a geometric evolution. POCBC also effectively enhance the voltage transfer gain in power-law terms. In the super-lift function, boost converters can operate only in constant case continuous conduction mode (CCM). Among the various converters for the efficient DC-DC conversion, under the category of Voltage-Lift converters and positive output and negative output Super Lift-converters, the 'positive output cascade boost converters' is highly suggested owing to its numerous advantages [2]. The boost converter supply high currents and the cascade boost converter can achieve high voltage gain. The high voltage of the cascade boost converter will be used for high battery voltage charging current [3]. The converter can hence operate in two different modes depending upon its energy storage capacity and the respective length of the switching period. These two modes are known as discontinues conduction and continuous modes.The DC-DC boost converter only requires four external components, such as Inductor, Electronic switch, Diode and output capacitor. These two operating modes are known as the discontinuous conduction mode (DCM) and continuous conduction mode (CCM) [4]. The conventional boost converter delivers low voltage gain while the positive output cascade boost converter can deliver high voltage gain. For high voltage DC applications, the boost converter cannot be used as it delivers low voltage gain. Because of the low voltage gain in boost converter, the positive output cascade boost converter is proposed. The positive output cascade boost converter is used for high gain voltage utilization applications such as EV, Battery charging and solar PV applications.

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2 PROPOSED SYSTEM TOPOLOGY

The general block diagram for the DC-DC conversion is shown in Figure 1.

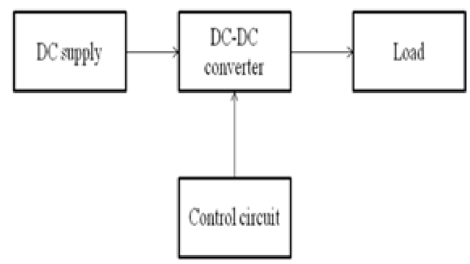

***Fig. 1**. General Block diagram for DC-DC Conversion*

There are five groups in the positive output cascade boost DC-DC converters as listed below. The detailed descriptions about each group are also elucidated.

1. Main series
2. Additional series
3 .Double series
4. Triple series
5. Multiple series

2.1. Main Series

The main series has group three categories: Elementary boost DC-DC converter, two stage boost DC-DC converter and three stage boost DC-DC converter.

2.1.1. Elementary DC-DC Boost Converter

The elementary DC-DC boost converter is the basic fundamental circuit where the output voltage is always higher than the input voltage. Figure 2 shows the circuit of elementary DC-DC Boost Converter.

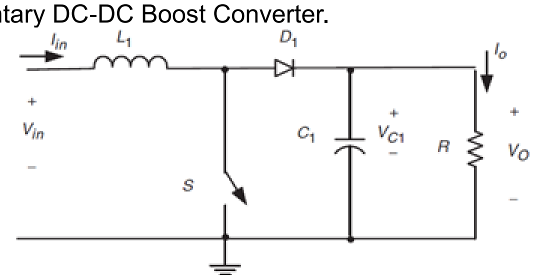

***Fig. 2**. Elementary DC- DC Boost converter*

The operation of boost converter comprises of two states such as ON state and OFF state as elucidated below:

ON state: In this mode, the switch is closed, resulting in increased inductor current.

OFF state: In the Off-state, the switch is open and the only path provides to inductor current is through the diode, the capacitor C and the load R. This results in transferring the energy during the ON-state into the capacitor.

The formula used to calculate the output voltage is,

Vo = Vs/1-α (1)

The equation representing the voltage gain is as follows:

$$G = \frac{Vo}{Vin} = \frac{2}{1-k}$$

(2)

2.1.2 Two Stage DC-DC Boost Converter

The two stage DC-DC boost converter is extended from the elementary DC-DC boost converter by adding the inductor, capacitor and diode. Figure 3 shows the circuit of two stage DC-DC boost converter.

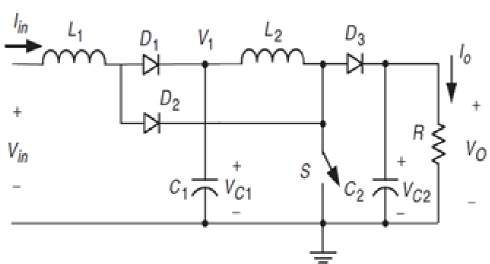

Fig. 3. *Two Stage Boost DC-DC Converter*

The potential between capacitor C_1 is charged to V1. The potential between capacitor C1 is $V1 = (1/(1-k)Vin)$. The voltage across capacitor C2 is charged to Vo. The current flowing through inductor L2 improves with voltage V1 during ON period kT and decreases with voltage $-(Vo - V1)$ during OFF period (1-k)T.

The equation (3) represents the voltage gain.

$$G = \frac{Vo}{Vin} = 2\left(\frac{1}{1-k}\right)2 \quad (3)$$

2.1.2 Three Stage Boost DC-DC Converter

The three stage DC-DC boost converter is extended from the two stage boost DC-DC converter by adding diode, capacitor and inductor. Figure 4 shows the circuit of three stage DC-DC boost converter.

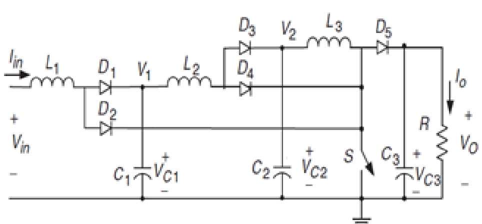

Fig. 4. *Three stage DC-DC boost converter.*

The potential between capacitor C1 is charged to V1. The potential between capacitor C1 is charged to V1 is $V1 = (1/(1-k))Vin$, and the potential between capacitor C2 is $V2 = (1/(1-k)2)Vin$. The potential between capacitor C3 is charged to Vo. The current flowing through inductor L3 improves with voltage V2 during ON period kT and decreases with voltage $-(Vo - V2)$ during OFF period (1-k)T.

Equation (4) represents the voltage gain.

$$G = \frac{Vo}{Vin} = 2\left(\frac{1}{1-k}\right)2 \quad (4)$$

2.2 Additional Series

By using two diodes and two capacitors, double enhance circuit (DEC) can be generated. The DEC is much capable to boost the output of DC/DC converter to transfer voltage gain. The additional series has three series combinations such as elementary additional boost, two stage additional boost and three stage additional DC-DC boost converter. Figure 5 shows the configuration of DEC.

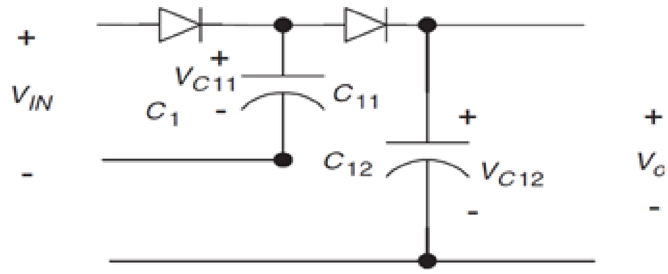

Fig. 5. *Double Enhance Circuit (DEC)*

2.2.1 Elementary Additional DC-DC Boost Converter

The elementary additional boost DC-DC converter is extended from the elementary boost DC-DC converter by adding double enhance circuit. Figure 6 shows the circuit of elementary additional DC-DC boost converter.

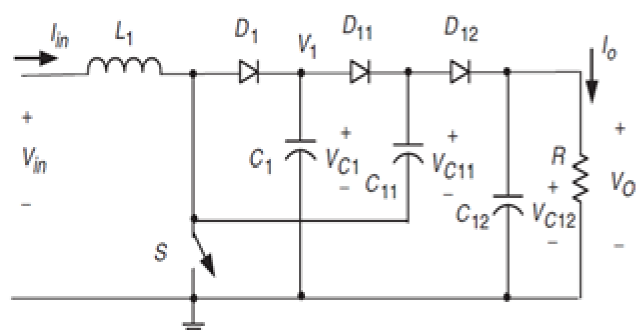

Fig. 6. *Elementary Additional DC-DC Boost Converter*

The potential between capacitors C1 and C11 is charged to V1 and the potential between capacitor C12 is charged to $Vo = 2V1$. The current iL1 flowing through the inductor L1 improves with voltage Vin during ON period kT and decreases with voltage $-(V1 - Vin)$ during OFF period (1-k)T.

Equation (5) represents the voltage gain,

$$G = \frac{V_O}{V_{in}} = \frac{2}{(1-K)} \quad (5)$$

2.2.2 Two Stage Additional DC-DC Boost Converter

The two stage additional DC-DC boost converter is extended from the two stage DC-DC boost converter by adding double enhance circuit. Figure 7 shows the circuit of two stage additional DC-DC boost converter.

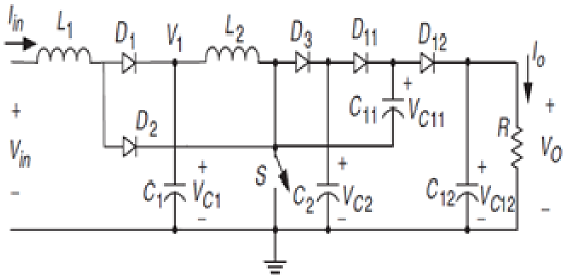

***Fig. 7**. Two – Stage Additional DC-DC Boost Converter*

The potential between capacitor C1 is charged to V1.The potential between the capacitor C1 is $V1 = (1/(1-k))Vin$. The potential between capacitor C2 and capacitor C11 is charged to $V2 = V1/(1-k) = (1/(1-k))2Vin$ and the potential between capacitor C12 is charged to Vo. The current flowing through the inductor L2 improves with voltage V1 during ON period kT and decreases with voltage $-(V2 - V1)$ during OFF period (1-k)T.

Equation (6) represents the voltage gain,

$$G = \frac{V_O}{V_{in}} = 2\left(\frac{1}{1-k}\right)2 \quad (6)$$

2.2.3 Three Stage Additional DC-DC Boost Converter

Three stage additional boost DC-DC converter was extended from the three stage boost DC-DC converter by adding double enhance circuit. Figure 8 shows the circuit of three stage additional DC-DC boost converter.

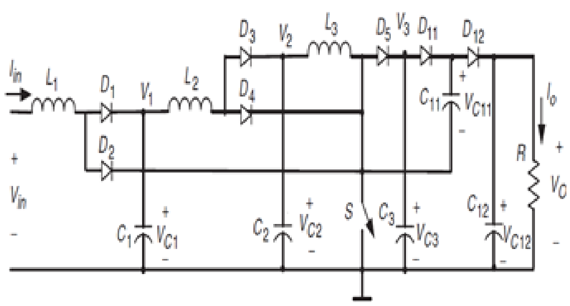

***Fig. 8**. Three-stage Additional DC-DC Boost Converter.*

The potential between capacitor C1 is charged to $V1 = (1/(1-k))Vin$, and the potential between capacitor C2 is $V2 = (1/(1-k)2)Vin$. The potential between capacitors C3 and C11 is charged to $V3 = V2/(1-k) = (1/(1-k))3Vin$. The potential between capacitor C12 is charged to Vo. The current flowing through inductor L3 improves with voltage V2 during ON period kT and decreases with voltage $-(V3 - V2)$ during OFF period (1-k)T.

Equation (7) represents the voltage gain,

$$G = \frac{V_O}{V_{in}} = 2\left(\frac{1}{1-k}\right)3 \quad (7)$$

2.3 Double Series

The POCB-double series was extended from corresponding circuits by adding double enhance circuit in each stage circuit. The double series has two types, two stage double boost and three stage double boost DC-DC converter.

2.3.1 Two Stage Double Boost DC-DC Converter

The two stage double boost DC-DC converter was extended from the two stage DC-DC converter by adding double enhance circuit. Figure 9 shows the circuit of two stage double boost DC-DC converter.

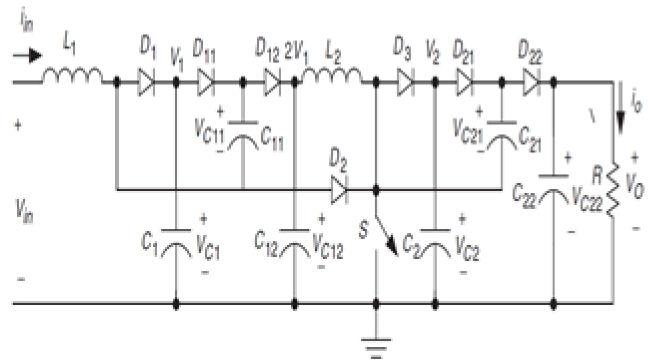

***Fig.9**. Two – Stage Double Boost DC-DC Converter*

The potential between capacitor C1 and capacitor C11 is charged to $V1 = (1/(1-k))Vin$. The potential between capacitor C12 is charged to 2V1. The current flowing through inductor L2 improves with voltage 2V1 during ON period kT and decreases with voltage $-(V2 - 2V1)$ during OFF period (1-k)T.

Equation (8) represents the voltage gain,

$$G = \frac{V_O}{V_{in}} = \left(\frac{2}{1-k}\right)2 \quad (8)$$

2.3.2 Three Stage Double Boost DC-DC Converter

The three stage double boost DC-DC converter was extended from the three stage boost DC-DC converter by adding double enhance circuit. Figure 10 shows the circuit of three stage double boost DC-DC converter.

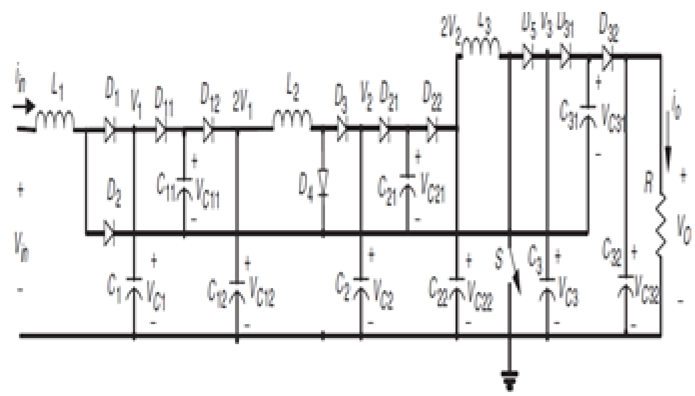

***Fig. 10**. Three Stage Double Boost DC-DC Converter*

The potential between capacitor C1 and capacitor C11 is charged to V1=1/(1-k)Vin, and potential between capacitor C2 and C12 is$V2 = 2(1/(1-k))2Vin$.. The potential between capacitor C22 is $2V2 = (2/(1-k))2Vin$. The potential between capacitors C3 and C31 is charged to V3.The potential between capacitor C12 is charged to Vo. The current flowing through inductor L3 improves with voltage V2 during ON period kT and decreases with voltage $-(V3 - 2V2)$ during OFF period (1-k)T.

Equation (9) represents the voltage gain.,

$$G = \frac{V_O}{V_{in}} = \left(\frac{2}{1-k}\right)3 \quad (9)$$

2.4 Triple Series

The POCB-triple series was extended from corresponding circuits by adding double enhance circuit in each stage circuit. The triple series has two types, such as two stage triple boost and three stage triple boost DC-DC converter.

2.4.1 Two Stage Triple Boost DC-DC Converter

The two stage triple boost dc-dc converter was extended from the two stage boost dc-dc converter by adding double enhance circuit twice in each stage. Figure 11 shows the circuit of two stage triple boost DC-DC converter. The potential between capacitors C1 and C11 is V1= (1/(1-k))Vin. The potential between capacitor C14 is charged to 3V1 and the potential between capacitors C2 and C21 is charged to V2 and potential between capacitors C22 and C23 is charged to VC23=2V2.

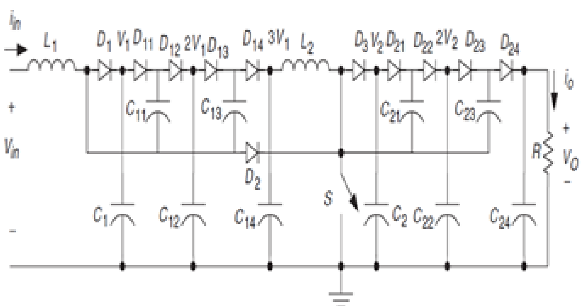

Fig. 11. *Two Stage Triple Boost DC-DC Converter.*

The current flowing through inductor L2 increases with voltage 3V1 during ON period kT, and decreases with the voltage -(V2-3V1) during the OFF period (1-k)T.
Equation (10) represents the voltage gain,

$$G = \frac{V_O}{V_{in}} = \left(\frac{3}{1-k}\right)2 \quad (10)$$

2.4.2 Three Stage Triple Boost DC-DC Converter

The three stage triple boost DC-DC converter was extended from the three stage boost DC-DC converter by adding double enhance circuit twice in each stage. Figure 12 shows the circuit of three stage triple boost DC-DC converter.

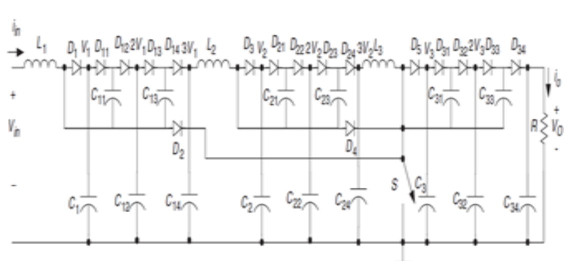

Fig. 12. *Three Stage Triple Boost DC-DC Converter*

The potential between capacitors C2 and C11 is $V2 = 3V1 = (3/(1-k))Vin$, and the potential between capacitor C24 is charged to 3V2. The potential between capacitors C3 and C31 is charged to V3 and potential between capacitors C32 and C33 is charged to VC33=2V3. The current flowing through inductor L3 increases with voltage 3V2 during ON period kT, and decreases with voltage $-(V3-3V2)$ during OFF period (1-k)T.
Equation (11) represents the voltage gain,

$$G = \frac{V_O}{V_{in}} = \left(\frac{3}{1-k}\right)3 \quad (11)$$

2.5 Multiple Series

The POCB-multiple series was extended from corresponding circuits by adding double enhance circuit j times in each stage circuit. The multiple series has three types, such as two stage multiple boost, three stage multiple boost and higher stage multiple DC-DC boost converter.

2.5.1 Two Stage Multiple DC-DC Boost Converter

The two stage multiple boost DC-DC converter was extended from the corresponding circuit of the main series by adding the DEC j times in each stage circuit. Figure 14 shows the circuit of two stage multiple DC-DC boost converter.

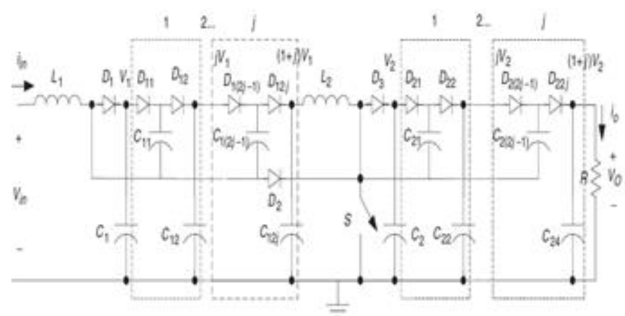

Fig. 13. *Two Stage Multiple DC-DC Boost Converter*

The potential between capacitors C1 and C11 is charged to $V1 = (1/(1-k))Vin$. The potential between capacitor C1 (2j) is charged to (1+j) V1. The current flowing through the inductor L2 improves with voltage (1+j) V1 during ON period KT and decreases with voltage $-[V2 - (1+j)V1]$ during OFF period (1-k)T.
Equation (12) represents the voltage gain,

$$G = \frac{V_O}{V_{in}} = \left(\frac{1+j}{1-k}\right)2 \quad (12)$$

Similar extensions can also be observed for three stage multiple boost and higher stage multiple DC-DC boost converter. Table I shows the comparison of output voltage for POCBC under main series. Subsequently, Table II-V shows the comparative analysis for additional, double, triple and multiple series respectively.

TABLE I: *MAIN SERIES*

ELEMENTARY DC-DC BOOST CONVERTER: INPUT = 5V	*OUTPUT = 15.95V*
TWO STAGE DC-DC CONVERTER: INPUT = 50V	*OUTPUT = 188.7V*
THREE STAGE DC-DC BOOST CONVERTER: INPUT = 50V	*OUTPUT = 291V*

TABLE II: *ADDITIONAL SERIES*

ELEMEMTARY DC-DC BOOST CONVERTER: INPUT = 50V	*OUTPUT = 299.2V*
TWO STAGE DC-DC BOOST CONVERTER: INPUT = 50V	*OUTPUT = 356.2V*
THREE STAGE DC-DC BOOST CONVERTER: INPUT = 50V	*OUTPUT = 411.4V*

***TABLE III:** DOUBLE SERIES*

TWO STAGE DC-DC BOOST CONVERTER: INPUT = 100V	*OUTPUT = 319.2V*
THREE STAGE DC-DC BOOST CONVERTER: INPUT = 100V	*OUTPUT = 187.4V*

***TABLE IV:** TRIPLE SERIES*

TWO STAGE DC-DC BOOST CONVERTER: INPUT = 100V	*OUTPUT = 313.7V*
THREE STAGE DC-DC BOOST CONVERTER: INPUT = 100V	*OUTPUT = 616.2V*

***TABLE V:** MULTIPLE SERIES*

TWO STAGE DC-DC CONVERTER: INPUT = 100V	OUTPUT = 314.6V

3 SIMULATION RESULT

Simulations are carried out in MATLAB/Simulink. Figure 14 shows the output waveform of three stage additional DC-DC boost converter. Under this configuration, the following specifications are used.

A 50V is given as input and it is stepped up to 411.4V.

Input voltage (Vs) = 50V
Capacitor (C) = 33µF
Inductor (L) = 1µH
Resistance (R) = 50Ω
Output voltage (Vo) = 411.4V

Extensive simulation study is undertaken for all the groups of POCBC. The results are listed in Table I-V.

***Fig. 14.** Three Stage Additional DC-DC Boost Converter*

Output Voltage Waveform

4 CONCLUSION

In some operations, high conversion rate are required. Different approaches and converter topologies can be attained to handle the complication. The design and development of Series DC – DC Converter - Positive Output cascade Boost converters has strongly established. It has been evaluated apparently and by scientific simulations using MATLAB software. The output results of simulations have been convinced with respect to higher voltage gain and improved conversion ratio. DC-DC converters will continue to play a major role in the technological advancement of vehicles in the future.

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